UNITED STATES DEPARTMENT OF AGRICULTURE
WAR FOOD ADMINISTRATION
Office of Marketing Services

RELATIONSHIPS OF COTTON FIBER PROPERTIES TO STRENGTH AND ELONGATION OF TIRE CORD

Preliminary Report

Washington, D. C.
June 1945

CONTENTS

UNITED STATES DEPARTMENT OF AGRICULTURE
WAR FOOD ADMINISTRATION
Office of Marketing Services

RELATIONSHIPS OF COTTON FIBER PROPERTIES TO STRENGTH AND ELONGATION OF TIRE CORD

By Robert W. Webb, principal cotton technologist, and Howard B. Richardson, associate cotton technologist, Cotton and Fiber Branch

SUMMARY AND CONCLUSIONS

This report completes the second segment of a broad study on the relationships of cotton fiber properties to manufacturing performance and to the quality of manufactured products. The findings represent 377 case-historied American upland cottons grown in duplicate, or 754 individually tested cottons, covering a wide range of growth conditions and fiber properties.

To understand and evaluate better the analyses and findings reported in this paper, reference should be made to the publication entitled "Relationships Between Properties of Cotton Fibers and Strength of Carded Yarns," the first report of this series. Detailed information is given there as to the samples; fiber, yarn, and spinning tests; statistical methods, terms, and measures; and the interrelationships occurring between various pairs of the fiber properties.

The fiber, yarn, and cord tests, and the spinning, plying, and cabling processes were performed by standardized methods under controlled atmospheric conditions.

By using multiple, partial, and simple correlation analyses, comprehensive studies have been made of the relationship and the contribution of a number of cotton fiber properties, separately and in various combinations, to the strength of 23/5/3 carded tire cord, to the percentage of elongation of such tire cord at the 10-pound load, and to the percentage of elongation at the point of rupture.

The fiber properties included are upper quartile length, coefficient of length variability, strength, fineness, percentage of mature fibers, and grade. Mean fiber length and staple length also have been considered in connection with tire-cord strength.

A coefficient of multiple linear correlation of 0.920 has been found for the relationship existing between the strength of the tire cord and the six collective fiber properties. This is relatively high, 84.6 percent of the total variance in the tire-cord strength of these cottons being accounted for by the fiber properties considered.

Essentially the same high correlation has been found for the relationship between the tire-cord strength and the four collective fiber properties of strength, fineness, coefficient of length variability, and grade as was obtained with the six fiber properties. The total variance in tire-cord strength explainable by those four fiber properties is 84.5 percent.

With other combinations of fiber properties, the coefficients of correlation are less and the amount of explainable variance in tire-cord strength is reduced.

The results of simple correlation analyses indicate relatively low or poor correlation between any one of the fiber properties and tire-cord strength. The fiber properties, however, vary considerably in this particular.

The fiber properties rank in order of importance to tire-cord strength, as follows: Fiber strength, coefficient of length variability, grade of cotton, fiber fineness, percentage of mature fibers, and upper quartile length. The contribution of the percentage of mature fibers and of upper quartile length to tire-cord strength is statistically insignificant.

When expressed in practical units of measure, as based on the six fiber-property equation, the average effect of change in each fiber property on the strength of 23/5/3 tire cord, while the other fiber properties are held constant, has been found to be as follows: Lowering the grade of cotton by one grade, decreases the strength of 23/5/3 tire cord by 0.30 pound; an increase of 1/32 inch in upper quartile length, causes no significant change in such cord strength; an increase of 1 percent in the coefficient of length variability, decreases the cord strength by 0.23 pound; an increase of 1 microgram per inch in fiber weight, decreases the cord strength by 0.76 pound (the coarser the fiber, the weaker the cord); an increase of 1 percent in the percentage of mature fibers, produces practically no effect on the cord strength; and an increase of 1,000 pounds per square inch in fiber strength, increases the cord strength by 0.18 pound.

The foregoing results, expressed in another manner, show that an increase of 1 pound in the strength of 23/5/3 tire cord follows by raising the grade of cotton by 3-1/4 steps; by decreasing the coefficient of length variability by 4.42 percent; by decreasing the fiber weight per inch by 1.32 micrograms (the finer the fiber, the stronger the cord); or by increasing the fiber strength by 5,600 pounds per square inch.

Twenty-three regression equations have been developed from which estimated strength of 23/5/3 tire cord may be predicted on the basis of one or more fiber properties. The precision of each of these equations is reported, together with the coefficients of correlation and determination.

The best estimating equation is that involving all six fiber properties. This equation has a precision indicating that, in two-thirds of the cases, the estimate can be expected to be within $\pm$ 0.78 pound of the actual cord strength. The result compares with $\pm$ 1.21 pounds for the best one fiber-property equation involving fiber strength.

As shown by the results from analyses involving fewer than six fiber properties, grade of cotton, percentage of mature fibers, and upper quartile length may be omitted from the regression equation without any appreciable loss of accuracy of estimates or predictions.

Supplementary equations have been derived from analyses of the 25 shortest cottons in the series, the 25 longest, and the 30 having practically equal fiber strength, in an effort to study further the effect of fiber length on the strength of tire cord. The results obtained confirm the previous findings, namely, that fiber length is of little or no importance, as such, to tire-cord strength. It should be emphasized, however, that as a practical matter, fiber length as determined by laboratory methods and, more particularly, staple length as designated by the classer provide an essential basis for the selection of cottons to meet the requirements of specific roll settings and drafts in manufacturing organizations. In addition, staple length serves as a useful basis for the selection of cottons for tire cord and other uses because of the fact that other fiber properties, such as fiber fineness and tensile strength, are generally associated with fiber length.

In the light of the evidence presented, it would appear that the "ply-and cabled" construction of tire cord gives, in effect, continuity to the cotton fibers composing it and thereby eliminates practically any opportunity for fiber lengths, per se, to make an appreciable contribution to the strength of tire cord, as in the case with single cotton yarns. When an increase in tire-cord strength accompanies an increase in upper quartile length or staple length, as frequently is the case, it is due to an associated increase in fiber fineness or fiber strength, or both, rather than to the increase in fiber length itself.

None of the equations involving separate fiber properties gives estimates of tire-cord strength precise enough to put much reliance in results obtained on the basis of any one fiber property alone.

The equations reported in reference to the strength of 23/5/3 tire cord are based on methods of either linear multiple or simple correlation analyses. However, the interpretations made are considered reliable, since studies involving methods of curvilinear correlation analyses failed to reveal any improvement over the high correlation ($R = 0.920$) found by regular linear correlation methods to exist between tire-cord strength and the fiber properties considered.

A relatively high positive correlation has been found to exist between the strength of tire cord and the skein strength of 23s single carded yarns, representing the respective cottons spun with optimum twist multipliers in relation to their staple lengths. The coefficient of correlation is + 0.897, and 80 percent of the total variance in the tire-cord strength from this series of cottons may be explained by yarn strength.

An equation is given for estimating the strength of tire cord from only a knowledge of the strength of single yarn. The equation indicates that an increase of 1 pound in the strength of 23s yarn increases the strength of 23/5/3 tire cord by 0.123 pound or approximately 1/8 pound. On the basis of the standard error for this equation, the estimated strengths of such tire cord would be expected to fall within $\pm$ 0.87 pound of the actual values in two-thirds of the cases.

A coefficient of multiple linear correlation of 0.679 has been found for the relationship between the percentage of tire-cord elongation at the 10-pound load and the six fiber properties considered. This is relatively low, only 46 percent of the total variance in this tire-cord elongation being explained by the fiber properties.

About as high a correlation has been found for the relationship between the tire-cord elongation at the 10-pound load and the two fiber properties of fineness and strength, as was obtained with the six fiber properties.

The results of simple correlation analyses indicate relatively low or poor correlation between any one of the fiber properties and tire-cord elongation at the 10-pound load. Three of the six simple coefficients are statistically insignificant, namely those for percentage of mature fibers, grade, and coefficient of length variability.

According to the partial correlation coefficients, only two fiber properties significantly affect tire-cord elongation at the 10-pound load. Ranked in order of importance they are fiber strength and fiber fineness.

Similar studies have been made of the percentage of elongation of tire cord at the point of rupture in relation to the fiber properties. The over-all correlation is a little less than that at the 10-pound load.

According to the partial correlation coefficients, four fiber properties significantly affect tire-cord elongation at the point of rupture. Listed in order of importance, they are as follows: Fiber strength, fiber fineness, coefficient of length variability, and grade.

Although the correlation coefficients based on linear relationships between the six fiber properties and tire-cord elongation at the 10-pound load, as well as at the point of rupture, are relatively low, no indication of any higher values was obtained when curvilinear analysis was applied to the data.

In the light of the findings obtained, it would appear that tire-cord elongation is due either to some one or more fiber properties not considered in these analyses - as fiber elongation and elasticity - or else that elongation is more a function of the construction of tire cord than it is of fiber properties.

A fairly high positive relationship has been found to exist between the two elongation measures of 23/5/3 tire cord, the coefficient of simple correlation being + 0.871.

A small but significant negative relationship occurred between the strength of this tire cord and percentage of elongation at the 10-pound load. An insignificant positive relationship, however, appeared between tire-cord strength and elongation at the point of rupture.

Each increase of 1 percent in tire-cord elongation at the 10-pound load is associated with a reduction of 0.58 pound in tire-cord strength; and each increase of 1 percent in the tire-cord elongation at the point of rupture is associated with an increase of only 0.08 pound in tire-cord strength.

Correlation analyses reveal an insignificant negative relationship between tire-cord elongation at the 10-pound load and skein strength of 23s carded single yarns, representing the respective cottons spun with optimum twist in relation to their staple lengths. On the other hand, a small positive but significant relationship has been found to exist between tire-cord elongation at the point of rupture and the strength of such singles yarn.

In considering the equations, statistical values, and conclusions presented in this paper, it should be understood that they refer only to one construction of tire cord, namely 23/5/3, and only to American upland cottons. What the results would be from similar analyses with other constructions of tire cord, of which there are many varied and specialized types, or with other growths of cotton, is problematical.

INTRODUCTION

In the first report of this series 1/, multiple linear correlation coefficients of 0.933 and 0.936 were reported for the relationships existing between six cotton fiber properties and the skein strength of 22s and 60s carded yarn, representing a large number and wide range of American upland cottons. The six fiber properties accounted for 87 percent of the total variance in the strength of the 22s yarn and 88 percent in that of the 60s yarn, thus leaving only 12 or 13 percent of the yarn strength variance as unexplainable by the fiber properties studied and, presumably, as largely attributable to other fiber properties. With both counts of yarn, fiber strength ranked first in importance to yarn strength, followed in order by coefficient of length variability, upper quartile length, fineness, grade, and percentage of mature fibers.

As in the case of yarns, precise information is needed on the quantitative relationships of cotton fiber properties to strength as well as to elongation of tire cord. More particularly, there is need to know: How much correlation actually occurs between fiber properties and each of those tire-cord properties? Which fiber property is the most important to the tire-cord properties and which one is the least? What is the rank of importance for the other contributing fiber properties? Is the order of importance of the fiber properties the same for both tire-cord strength and elongation, or is it different? Are the relationships, rank of importance, and number of significantly contributing fiber properties the same with tire-cord elongation at the 10-pound load as at the point of rupture, or are they different? And, how do these fiber-property ranks in reference to different tire-cord properties compare with those for the strength of 22s and 60s carded yarn made from the same cottons?

As a means of providing answers to such questions, correlation analyses have been made of the data representing the same series of American upland cottons as was done in the previous study with respect to yarn strength.

SAMPLES, TESTS, AND ANALYSES

The basic data used in the statistical analyses in this report were obtained through extensive Federal-State cooperative effort. The principal agencies cooperating in this study provided the samples and basic data involved, as well as assistance, as follows: The Bureau of Plant Industry, Soils, and Agricultural Engineering selected the varieties and growth locations, and produced and ginned all samples. The various Southern State

---

1/ "Relationships Between Properties of Cotton Fibers and Strength of Carded Yarns," by Robert W. Webb and Howard B. Richardson, Cotton and Fiber Branch, USDA and WFA, pp. 58, March 1945. (Processed.)

experiment stations and substations cooperated in setting up the field work and in the production of the cottons. The Cotton and Fiber Branch of the Office of Marketing Services, laboratories of which are operated jointly with the Bureau of Plant Industry, Soils, and Agricultural Engineering, the Agricultural and Mechanical College of Texas, and the Clemson Agricultural College of South Carolina, conducted the spinning and fiber tests.

For a better understanding and evaluation of the analyses and findings here reported, reference to the first report of this series will be helpful 2/. It contains more complete details and literature citations than here given with respect to the varieties, samples, and growth locations represented; the methods and conditions used in making the fiber, spinning, and yarn tests; and the methods, terms, measures, and scatter diagrams used in the statistical analyses. Information also is given in the first report on the interrelationships existing between the various fiber properties, as revealed by the correlation values reported for the 15 pairs of fiber properties considered. Those data are of basic interest to the interpretations in this report.

Included in the previous study with 22s and 60s carded warp yarn manufactured from cottons of the same series, were 384 averages of duplicate lots, representing 768 individually tested cottons. A slightly smaller number of cottons and averages, however, had to be used in the tire-cord study, because the sample of cotton was too small in 14 individual cases, or 7 duplicate lots, to permit the manufacture of tire cord.

In addition to the several counts of yarn, representing the optimum twist for a particular staple length and previously reported for each cotton of the series, 3/ a 23s yarn with a constant twist multiplier also was spun. With this yarn, samples of tire cord were made according to the ASTM standard specifications 4/ which were in existence at the time of the tests and which were, in reference to construction and cotton, as follows: "The cord shall be that known in the trade as 23/5/3 construction. The actual size of the single yarn shall be so adjusted as to give the finished size of the cord specified. These specifications are based on cord made from American Middling cotton of good hard character with a staple length of 1-1/16 inches. Yarns shall be single carded."

2/ See footnote 1/, p. 6.

3/ See footnote 1/, p. 6.

4/ ASTM Standards on Textile Materials. Standard Specifications for 23/5/3 Carded American Tire Cord. D298-29, prepared by Committee D-13, pp. 127-129, Sept. 1937. (Published and issued annually by the American Society for Testing Materials, Philadelphia, Pa.) Note: These specifications, more recently, have been deleted from the publication cited.

Accordingly, the yarns used in the manufacture of this tire cord were spun with a constant twist multiplier, namely 4.0, which our spinning results have shown to give maximum yarn strength for cottons in the range of the staple length designated in the specification. The final net figures regarding the other twists employed in the manufacture of this tire cord are as follows: Ply-yarn (composed of five strands of 23s single yarn), 18 turns per inch in the same direction as the twist in the single yarns; cord (composed of three 5-ply yarns), eight turns per inch in the opposite direction from the twist in the ply and single yarns.

Laboratory tests were made on the tire cord as follows: Strength, elongation at the 10-pound load, elongation at the point of rupture, yards per pound, gage, and moisture determinations. Twist measurements on the ply, as well as on the cable material, were made on each sample mainly as a control measure. All tests on the cord were conducted in accordance with standard methods in existence at the time, wherever such standards applied, as described in an ASTM publication on this subject, 5/ and under standard atmospheric conditions of 65 percent relative humidity and a temperature of 70° F.

The machine used in determining the strength and elongation of the tire cord was a standard Single Strand Tester of the pendulum type, equipped with special cam clamps. The tester had a capacity of 25 and 50 pounds, but only the 25-pound capacity was used for these tests. The lower jaws moved at a speed of 12 inches per minute.

The solid cylindrical snubbing surfaces of the clamps were one-half inch in diameter and so arranged as to permit the application of an initial tension of 4 ounces on the test specimen. A starting load of 4 ounces constitutes a very small weight, barely sufficient to take the kinks out of the test specimen.

Twenty-five tests were made for each lot of cotton and the averages so obtained were taken to represent the tire-cord strength and elongation for a particular cotton. The length of the test specimen was 10 inches in all cases. Strength and elongation tests were made simultaneously on the same specimen, elongation readings being made from an autographic chart at the 10-pound load and at the point of tire-cord rupture.

The percentage of tire-cord elongation at the 10-pound load was calculated by dividing the stretch of the cord in inches at that load by 10 inches, or the original length of sample between the "bite" of the clamps of the strength-testing machine, and multiplying the quotient so obtained

---

5/ ASTM Standards on Textile Materials. Standard Methods of Testing and Tolerances for Tire Cord, Woven and on Cones. D179-33, prepared by Committee D-13, pp. 117-126, Sept. 1937. (Published and issued annually by the American Society for Testing Materials, Philadelphia, Pa.)

by 100. The same procedure was used in calculating the tire-cord elongation at the point of rupture, the only difference being that the stretch at the break of the cord was used.

DATA USED IN STATISTICAL ANALYSES

The extent to which the cottons used in this study varied in their measureable fiber and tire-cord properties is revealed by the data summarized in table 1. It will be noted that the fiber properties cover relatively wide ranges, insofar as American upland cottons are concerned.

It also is of interest to note the comparatively wide ranges of tire-cord strength and elongation furnished by these cottons. For a standard construction of 23/5/3 carded tire cord, such values give evidence of the influence over a relatively wide range of many combinations of fiber properties in the raw cottons from which the tire cords were manufactured.

Omission of the seven duplicate lots of cotton, previously mentioned, failed to cause any significant disturbance in the values for the range, mean, and frequencies of the respective fiber properties, as compared with those for the entire series of 384 averages. Therefore, insofar as the fiber properties are concerned, direct comparison of the findings presented herein for strength and elongation may be made with those previously reported 6/ for strength of single yarns.

In comparing the findings pertaining to the fiber-cord relationships with those concerning fiber-yarn relationships, however, some caution should be exercised because of a lack of precisely comparable conditions in the two cases. That is, the single yarns previously reported were manufactured with a twist multiplier which, in relation to the staple of its raw cotton, gave maximum yarn strength. On the other hand, the yarns that composed the tire cord were all manufactured with a constant twist multiplier, namely 4.0, regardless of staple length. These details and possible effects will be considered further in the Discussion.

For convenience in presentation, grade is referred to as a fiber property. Grade, however, is not a separate fiber property in the accepted technical sense of fiber length or fiber strength.

RELATIONSHIPS BETWEEN STRENGTH OF TIRE CORD AND VARIOUS COMBINATIONS OF FIBER PROPERTIES

In order to measure and express the fiber-cord property relationships, it is necessary to develop a series of regression equations in systematic manner. The multiple regression equations that have been developed, representing six fiber properties, will be considered first; they will be followed in order by the equations representing certain combinations of 5,4, 3, and 2 fiber properties. These equations are listed in table 2, and are

---

6/ See footnote 1/, p. 6.

Table 1. - Range and frequency of 8 measured fiber properties and of strength and elongation of 23/5/3 carded tire cord of American upland cotton, crop years 1935-37

(Data, as represented by these frequencies, refer to 377 averages of cottons grown in duplicate and were used in multiple and simple correlation analyses.)

Grade			Staple length			Upper quartile length		Mean length		Length variability	
Name	Class interval	Relative frequency		Inches	Relative frequency	Inches	Relative frequency	Inches	Relative frequency	Coefficient	Relative frequency
Strict Middling	3.5- 4.4	0.5	5/8	0.594-0.656	0.3	0.70-0.79	0.5	0.50-0.59	0.3	21-23	3.2
Middling	4.5- 5.4	20.4	11/16	0.657-0.718	0.0	0.80-0.89	6.6	0.60-0.69	2.1	24-26	32.4
Strict Low Middling	5.5- 6.4	42.3	3/4	0.719-0.781	2.1	0.90-0.99	12.2	0.70-0.79	11.7	27-29	35.5
Low Middling	6.5- 7.4	24.9	13/16	0.782-0.843	5.8	1.00-1.09	35.6	0.80-0.89	30.0	30-32	15.4
Strict Good Ordinary	7.5- 8.4	6.6	7/8	0.844-0.906	16.2	1.10-1.19	26.6	0.90-0.99	37.1	33-35	9.5
Good Ordinary	8.5- 9.4	2.9	15/16	0.907-0.968	26.8	1.20-1.29	13.5	1.00-1.09	14.8	36-38	3.7
Below Grade	9.5-10.4	2.4	1	0.969-1.031	30.5	1.30-1.39	3.7	1.10-1.19	3.2	39-41	0.3
			1-1/16	1.032-1.093	9.0	1.40-1.49	1.3	1.20-1.29	0.8		
			1-1/8	1.094-1.156	5.8						
			1-3/16	1.157-1.218	2.4						
			1-1/4	1.219-1.281	0.8						
			1-5/16	1.282-1.344	0.3						
Mean : Strict Low Middling minus		(6.20)	Mean	31/32 inch		Mean	1.087 inches	Mean	0.909 inch	Mean	28.2
Maximum: Below Grade - - - - - -		(10.00)	Maximum	1-5/16 inches		Maximum	1.45 inches	Maximum	1.23 inches	Maximum	40.0
Minimum: Strict Middling minus - -		(4.33)	Minimum	5/8 inch		Minimum	0.73 inch	Minimum	0.59 inch	Minimum	22.0

Fiber fineness		Percentage of mature fibers		Fiber strength		Tire-cord strength		Percentage of tire-cord elongation			
								At 10-pound load		At point of rupture	
Micrograms per inch	Relative frequency	Class interval	Relative frequency	1,000 lbs. per square inch	Relative frequency	Pounds	Relative frequency	Class interval	Relative frequency	Class interval	Relative frequency
2.7-3.1	0.5	48-52	1.1	58-62	0.8	9.0-10.9	0.3	7.0- 7.9	1.1	11.0-11.9	0.3
3.2-3.6	5.9	53-57	1.6	63-67	4.0	11.0-12.9	2.9	8.0- 8.9	5.8	12.0-12.9	3.7
3.7-4.1	13.0	58-62	6.6	68-72	14.0	13.0-14.9	4.5	9.0- 9.9	7.2	13.0-13.9	10.6
4.2-4.6	24.1	63-67	13.0	73-77	22.8	15.0-16.9	17.8	10.0-10.9	24.1	14.0-14.9	12.2
4.7-5.1	31.0	68-72	19.6	78-82	22.8	17.0-18.9	42.1	11.0-11.9	29.7	15.0-15.9	20.2
5.2-5.6	18.8	73-77	35.5	83-87	18.3	19.0-20.9	28.9	12.0-12.9	23.3	16.0-16.9	25.2
5.7-6.1	5.6	78-82	19.9	88-92	11.7	21.0-22.9	3.5	13.0-13.9	7.7	17.0-17.9	16.2
6.2-6.6	0.8	83-87	2.7	93-97	5.0			14.0-14.9	1.1	18.0-18.9	7.7
6.7-7.1	0.3			98-102	0.3					19.0-19.9	3.4
				103-107	0.3					20.0-20.9	0.5
Mean	4.74	Mean	72.3	Mean	79.5	Mean	17.9	Mean	11.34	Mean	16.01
Maximum	6.9	Maximum	86.0	Maximum	103.0	Maximum	21.4	Maximum	14.58	Maximum	20.40
Minimum	2.8	Minimum	48.0	Minimum	61.0	Minimum	10.8	Minimum	7.73	Minimum	11.90

Table 2. - Regression equations and statistical values showing the relation between strength of 23/5/3 carded tire cord and 8 separate and variously combined fiber properties of American upland cotton, crop years 1935-37

(Results are based on multiple or simple linear correlation analyses of 377 averages of cottons grown in duplicate and equations are ranked according to decreasing coefficients of correlation and increasing standard errors.)

Identification			Regression Equations Involving										Statistical Values		
				Coefficients for Independent Variables of											
Number	Rank	Fiber properties	(X'_{23}) = Estimated strength, 23/5/3 tire cord, lbs.	(X_1) Grade of cotton, by number	(X_2) Upper quartile length, in inches	(X_{10}) Staple length, in inches	(X_{11}) Mean length, in inches	(X_3) Coefficient of length variability, in percent	(X_4) Fiber fineness, in micrograms per inch	(X_{35}) Percentage of mature fibers	(X_6) Fiber tensile strength, in 1000 pounds per sq. in.	(A) Constant	(S) Standard error of estimate, in pounds	(R, r) Coefficient of correlation	(R^2, r^2) Coefficient of determination
(1)	1	6	X'_{23} =	-0.304	-0.225	—	—	-0.226	-0.756	-0.011	+0.179	+ 16.55	± 0.78	0.920 ± 0.008	0.846 ± 0.015
(2)	2	5	X'_{23} =	- .299	—	—	—	- .225	- .713	- .012	+ .180	+ 16.08	± 0.78	.919 ± .008	.845 ± .015
(3)	3	5	X'_{23} =	- .315	- .469	—	—	- .219	- .845	—	+ .179	+ 16.34	± 0.78	.919 ± .008	.845 ± .015
(8)	4	4	X'_{23} =	- .304	—	—	—	- .215	- .769	—	+ .181	+ 15.14	± 0.78	.919 ± .008	.845 ± .015
(4)	5	5	X'_{23} =	- .237	+2.216	—	—	- .213	—	- .040	+ .195	+ 10.39	± 0.81	.912 ± .009	.832 ± .016
(5)	6	5	X'_{23} =	—	+ .777	—	—	- .274	- .544	- .022	+ .184	+ 14.28	± 0.82	.910 ± .010	.829 ± .018
(9)	7	3	X'_{23} =	—	—	—	—	- .269	- .767	—	+ .183	+ 14.60	± 0.82	.909 ± .009	.826 ± .016
(10)	8	3	X'_{23} =	—	+2.735	—	—	- .213	—	—	+ .204	+ 4.75	± 0.86	.899 ± .010	.808 ± .018
(11)	9	3	X'_{23} =	- .303	—	—	—	- .168	—	—	+ .206	+ 8.10	± 0.89	.894 ± .010	.799 ± .018
(12)	10	2	X'_{23} =	—	—	—	—	- .221	—	—	+ .209	+ 7.57	± 0.92	.883 ± .011	.780 ± .019
(6)	11	5	X'_{23} =	- .609	+ .836	—	—	—	- .495	+ .031	+ .190	+ 5.76	± 0.95	.875 ± .012	.766 ± .021
(13)	12	2	X'_{23} =	- .616	—	—	—	—	—	—	+ .202	+ 5.67	± 1.01	.859 ± .013	.739 ± .022
(14)	13	2	X'_{23} =	—	—	—	—	—	- .186	—	+ .197	+ 3.13	± 1.20	.793 ± .019	.628 ± .030
(16)	14	1	X'_{23} =	—	—	—	—	—	—	—	+ .203	+ 1.75	± 1.21	+.791 ± .019	.625 ± .030
(7)	15	5	X'_{23} =	- .489	-5.210	—	—	-.288	-2.478	+ .001	—	+ 46.40	± 1.41	.701 ± .026	.491 ± .036
(15)	16	2	X'_{23} =	—	+4.175	—	—	- .186	—	—	—	+ 18.61	± 1.77	.436 ± .042	.190 ± .037
(17)	17	1	X'_{23} =	—	—	—	—	—	-1.152	—	—	+ 23.35	± 1.82	-.380 ± .044	.144 ± .033
(18)	18	1	X'_{23} =	—	—	—	—	- .198	—	—	—	+ 23.48	± 1.85	-.352 ± .045	.124 ± .032
(19)	19	1	X'_{23} =	—	—	—	+ 6.566	—	—	—	—	+ 11.93	± 1.85	+.352 ± .045	.124 ± .032
(20)	20	1	X'_{23} =	- .642	—	—	—	—	—	—	—	+ 21.87	± 1.85	-.351 ± .045	.123 ± .032
(21	21	1	X'_{23} =	—	+4.611	—	—	—	—	—	—	+ 12.88	± 1.89	+.286 ± .047	.082 ± .027
(22)	22	1	X'_{23} =	—	—	+5.977	—	—	—	—	—	+ 12.12	± 1.90	+.277 ± .048	.077 ± .027
(23)	23	1	X'_{23} =	—	—	—	—	—	—	- .035	—	+ 20.42	± 1.95	-.117 ± .051	.014 ± .012
(24)	24	0	X'_{23} =	—	—	—	—	—	—	—	—	+ 17.89	± 1.97	—	—

ranked according to their decreasing coefficients of correlation and increasing standard errors of estimate. The coefficients of determination, as well as the standard errors associated with the different coefficients, also are shown in the tabulation.

Six fiber properties. One equation has been developed for six fiber properties, namely

$$(1)\quad X'_{23} = 16.55 - .304X_1 - .225X_2 - .226X_3 - .756X_4 - .011X_{35} + .179X_6 \qquad \overset{S}{\pm 0.78}$$

Where X_1 = Grade of cotton, by number
X_2 = Upper quartile length, in inches
X_3 = Coefficient of length variability, in percent
X_4 = Fineness of fiber, in micrograms per inch
X_{35} = Percentage of mature fibers
X_6 = Fiber tensile strength in 1,000 pounds per square inch
X'_{23} = Estimated strength of 23/5/3 carded tire cord, in pounds

By inspection, or by substituting the mean value for any respective fiber-property symbol, it can readily be seen that fiber length and percentage of mature fibers have only a small effect on the estimate. The standard error, ± 0.78 indicates that, in about two-thirds of the cases, the cord strength may be estimated within this amount. This compares with a standard error of ± 1.21 for the best estimating equation involving one fiber property, namely strength.

The coefficient of correlation for equation (1) is 0.920 and the coefficient of determination is 0.846. The latter figure indicates that 85 percent of the variance in such cord strengths is accounted for by these six fiber properties. This result compares with 87 percent when the same six fiber properties for the same series of cottons are considered in connection with 22s yarn strength 7/. When only fiber strength is considered in simple correlation analysis, the coefficient of determination with respect to the strength of this tire cord is 0.625, indicating that 62 percent of the variance in cord strength is accounted for by this fiber property or the one which ranks first in importance to cord strength.

Five fiber properties. Correlation analyses between six combinations of five fiber properties resulted in equations (2), (3), (4), (5), (6), and (7). (See table 2.) These six equations reveal in a practical way the importance of the separate fiber properties since they compare the respective standard error associated with the omission of each fiber property with the standard error found for the six fiber properties, namely, ± 0.78. Thus, it is seen that upper quartile length, percentage of mature fibers, fiber fineness, and grade of cotton are each of little importance insofar as estimating the strength of 23/5/3 carded tire cord is concerned. The standard errors of equations (2), (3), (4), and (5) range from ± 0.78 to ± 0.82 and compare favorably with that obtained for the six fiber-property equation, namely, ± 0.78. Equation (6), having a standard error of ± 0.95 when coefficient of variability of length is omitted, shows that this property is of some importance to tire cord strength, whereas equation

---

7/ See footnote 1/, p. 6.

(7), having a standard error of ± 1.41 when fiber strength is omitted, shows that fiber strength is of considerable importance. In fact, fiber strength is more important than the combined effect of all five of the other fiber properties, as can be seen by comparing the standard errors of equations (16) and (7).

On the basis of the partial coefficients of correlation, which will be discussed later, various combinations of the fiber properties have been selected for study. Obviously, it would have been both impracticable and unnecessary to have studied the effect of all possible combinations of fiber properties, since this would have involved determining 63 different equations. Moreover, with the two substitutional measures for length, namely, staple length as designated by cotton classers and mean length as determined by the sorter, there would have been a total of 189 equations if all possible combinations had been used.

Four fiber properties. One equation (8), involving the omission of percentage of mature fibers and upper quartile length, has been derived for four fiber properties. The standard error of this equation is ± 0.78 and is the same as that when all six fiber properties are used. The corresponding coefficients of determination are 0.845 and 0.846. Thus, these figures indicate that just as great a percentage of the variance in cord strength is accounted for by the four fiber properties of strength, length variability, fineness, and grade as was found with all six fiber properties, including upper quartile length and percentage of mature fibers.

Since a fiber length array has to be made in connection with determining the coefficient of length variability, which is included in the four fiber-property equation referred to, only one kind of fiber test is avoided by using this equation, namely, the percentage of mature fibers. The omission of the latter test, however, represents a saving in both time and expense of one of the most tedious of the fiber measurements. Ordinarily, equation (3) instead of (8), would be used where only percentage of mature fibers is omitted, since the determination of upper quartile length is merely a short mathematical calculation requiring a few minutes of time, once the array is made.

Three fiber properties. Three equations, involving three fiber properties, have been developed. Equation (9) involves omission of grade, upper quartile length, and percentage of mature fibers. The standard error is ± 0.82 as compared with ± 0.78 when all six fiber properties are used. The respective coefficients of determination are 0.826 and 0.846, indicating that 83 percent of the variance in 23/5/3 cord strength is accounted for by coefficient of length variability, fiber fineness, and fiber strength, whereas 85 percent is accounted for when all six fiber properties are used.

Equation (10), which involves only two kinds of fiber tests, namely, those for length and strength, gives estimates slightly less precise than equation (9), the respective standard errors being ± 0.86 and ± 0.82. The

coefficient of determination for equation (10) indicates that 81 percent of the cord-strength variance is accounted for by the three fiber properties - upper quartile length, coefficient of length variability, and fiber strength, as compared with 85 percent when all six fiber properties are included.

Equation (11) gives estimates slightly less precise than equation (9), but appreciably less precise than that for the six fiber properties. This equation involves omission of upper quartile length, fineness, and percentage of mature fibers. The coefficient of determination in this instance is 0.799, thus indicating that 80 percent of the variance in the cord strength is accounted for by grade, coefficient of length variability, and fiber strength, as compared with 85 percent when all six fiber properties are used.

Two fiber properties. Four equations involving two fiber properties have been developed. Equation (12) includes coefficient of length variability and fiber strength. The standard error, $\pm$ 0.92, is somewhat larger than the $\pm$ 0.78 obtained when all six fiber properties are involved. The corresponding coefficients of determination are 0.780 and 0.846, which values indicate that 78 percent of the variance in cord strength is accounted for by fiber strength and length variability, whereas 85 percent of the variance in cord strength is explained by the six fiber properties. Thus, omitting grade, upper quartile length, fiber fineness, and percentage of mature fibers from the equation, entailed a loss of only 7 percent in the amount of variance in cord strength accounted for by these fiber properties.

Equation (13) involves grade of cotton and fiber strength. The standard error is $\pm$ 1.01 as compared with $\pm$ 0.78 when all six fiber properties are used. The corresponding coefficients of determination are 0.739 and 0.846, which indicate that 74 percent of the variance in cord strength is accounted for by grade of cotton and fiber strength in contrast with 85 percent of the variance accounted for by all six fiber properties. Thus, there is a loss of 11 percent in the amount of explainable variance in tire cord strength when upper quartile length, coefficient of length variability, fineness, and percentage of mature fibers are omitted from the equation.

The standard errors of equations (14) and (15) are too large to place much reliance on the estimates, the values being $\pm$ 1.20 and $\pm$ 1.77, respectively. Equation (15), involving length measurements alone - upper quartile length and coefficient of length variability - indicates that these two length factors in combination do not furnish a tool of sufficient reliability for estimating the strength of tire cord. Instead of comparing its standard error with that of equation (1), which involves six fiber properties and gives the most accurate estimate of those considered, the standard error may be compared with that of a single observation for the 377 observations of tire cord strength. This error is $\pm$ 1.97, as shown by equation (24) in table 2, and the average strength is 17.89 pounds. Thus, any estimated

value of tire-cord strength based on upper quartile length and coefficient of length variability would, on the average, be expected to be only + 0.20 pound better than that based on mean cord strength alone, without the consideration of any fiber properties at all.

RELATIONSHIPS BETWEEN STRENGTH OF TIRE CORD AND SEPARATE FIBER PROPERTIES

The correlation between each of the eight fiber properties and the strength of 23/5/3 tire cord has been determined. The statistical findings are shown in table 2, as are the equations, which are identified as (16), (17), (18), (19), (20), (21), (22), and (23).

These simple correlations indicate the apparent importance of each of the fiber properties to such tire-cord strength, when the effects of all other measured fiber properties are ignored, although all contributing fiber properties - whether measured or not - influence the strength of the cord. The highest simple correlation coefficient was found to exist between fiber strength and cord strength, the figure being + 0.791 $\pm$ 0.019, which indicates fair correlation between the two properties. The corresponding coefficient of determination is 0.625, which indicates that 62 percent of the variance in cord strength is accounted for by fiber strength alone. This compares with 85 percent when all six fiber properties are used in multiple linear correlation analysis of the same cottons.

The correlations between each of the other seven fiber properties and cord strength are poor and would account for only a small proportion of the variance in strength of the tire cord, such variance being less than 15 percent, as indicated by the coefficients of determination in table 2. With the exception of that involving fiber strength, the high standard errors of the regression equations, namely $\pm$ 1.82 to $\pm$ 1.95, indicate that little improvement in estimating cord strength from each fiber property alone is obtained over that of estimating it on the basis of the mean cord strength for this series of cottons, namely 17.89 pounds. A standard error of a single observation, equal to $\pm$ 1.97, is associated with the latter figure.

Although the results from the simple correlation analyses refer only to the "apparent" effect of the separate fiber properties in terms of tire-cord strength, since they are affected by interrelations existing between certain pairs of the fiber properties considered, as evidenced by the data presented in the first report of this series [8], they are of interest in revealing what to expect when only one fiber property at a time is used. The regression coefficients change appreciably, however, as additional variables are included in the equations, as may be readily seen by referring to those involving two or more fiber properties. The most reliable rank

---

8/ See footnote 1/, p. 6.

of importance of the separate fiber properties with respect to tire cord is established on the basis of the partial coefficients of correlation which will be presented and discussed later. There the effect of each fiber property is determined in connection with the six-fiber property equation, only after the effects of all the other considered fiber properties have been eliminated.

IMPORTANCE OF DIFFERENT FIBER PROPERTIES TO TIRE-CORD STRENGTH

It is evident from the foregoing that a large number of equations with diversified regression coefficients and constant values may be derived from the same data, depending on the number and nature of the fiber properties taken into consideration. It should be emphasized, therefore, that the measured importance reported for each fiber property in this paper, or any other paper, is subject to the restriction that it holds precisely only for the number and kind of fiber properties used, for the tests and test-conditions described, and for the units employed in measuring each fiber and yarn property. The importance of each fiber property discussed in the present chapter is based on analyses of data from which the six fiber-property equation (1) was derived.

There are a number of statistical measures that furnish a criterion for the determination of the importance of the various fiber properties, such as: Regression coefficients, beta coefficients, coefficients of separate determination, and coefficients of partial correlation. All of these have been calculated and considered in these studies but only the values for the first- and last-mentioned measures are included in this presentation. For the most part, the beta, separate, and partial coefficients of correlation are in general agreement and support similar conclusions. By definition and mathematics, however, the partial correlation coefficients are considered more reliable for this purpose than are the beta coefficients and coefficients of separate determination; hence, the values for the latter two statistical measures have been omitted from this presentation.

In connection with each of the equations listed in table 2, the coefficient of determination also is shown. This measure, when multiplied by 100, indicates the percent of tire-cord strength variance accounted for by the measured fiber properties considered in each equation and the relative importance of each combination of fiber properties with respect to tire-cord strength.

The regression coefficients shown in the equations indicate the amount of change in tire-cord strength resulting from a unit change in a separate fiber property. The magnitudes of the regression coefficients naturally vary with the units of measure employed with each kind of test and, therefore, can not be used directly for ranking the importance of the various fiber properties with respect to tire-cord strength. This measure, however, furnishes a practical and understandable yardstick for those unfamiliar with statistical methodology.

The regression coefficients of the six fiber-property equation (1) are listed in table 3, each being followed by its standard error. The magnitude of the standard error shown is less than one-third of the value for its regression coefficient in the case of four of the fiber properties, namely, grade, coefficient of length variability, fineness, and strength. This indicates that the regression coefficients in these instances are significant and not due to chance alone. In the case of upper quartile length and percentage of mature fibers, however, the standard errors are so large in relation to their respective regression coefficients as to suggest that the effects of these two fiber properties on tire-cord strength are negligible. As a matter of fact, in the case of upper quartile length, the size of the standard error is actually over twice the value of the regression coefficient.

In the light of the data summarized in table 4, as based on the regression coefficients of the six fiber-property equation (1), deductions of practical interest may be made in connection with the strength of tire cord, as follows:

Lowering the grade of the cotton by one grade decreases the strength of 23/5/3 carded tire cord by 0.30 pound;

An increase of 1/32 inch in the upper quartile length causes no significant change in tire-cord strength;

An increase of 1 percent in the coefficient of length variability decreases the strength of tire-cord by 0.23 pound;

An increase of 1 microgram per inch in fineness decreases the tire-cord strength by 0.76 pound (the coarser the fiber, the weaker the cord);

An increase of 1 percent in the percentage of mature fiber has practically no effect on the strength of tire cord; and

An increase of 1,000 pounds per square inch in fiber strength increases the strength of tire cord by 0.18 pound.

Expressing the results in another way, as shown in table 4, an increase of 1 pound in the strength of 23/5/3 tire cord results from each of the following:

Raising the grade of cotton by 3-1/4 steps;

Decreasing the coefficient of length variability by 4.42 percent;

Decreasing the fiber weight per inch by 1.32 micrograms (the finer the fiber, the stronger the cord); and

Increasing fiber strength by 5,600 pounds per square inch.

Table 3. - Importance of each of 6 measured cotton fiber properties with respect to strength of 23/5/3 carded tire cord for American upland cottons, crop years 1935-37

(These results were obtained from multiple linear correlation analyses of 377 averages of cottons grown in duplicate.)

Fiber properties	Regression coefficients 1/
Grade of cotton, by number	- 0.304 ± 0.048
Upper quartile length, in inches	- .225 ± .546
Coefficient of length variability, in percent	- .226 ± .016
Fiber fineness, micrograms per inch	- .756 ± .133
Percent of mature fibers	- .011 ± .009
Fiber strength, in 1,000 pounds per square inch	+ .179 ± .006

1/ Coefficients of the six fiber-property equation (1).

Table 4. - Effect of change in each of 6 measured cotton fiber properties on the strength of 23/5/3 carded carded tire cord for American upland cottons, crop years 1935-37

(These results are based on regression coefficients obtained from multiple linear correlation analyses of 377 averages of cottons grown in duplicate.)

Change in tire-cord strength 1/		Change in fiber property of					
		Grade of cotton	Upper quartile length	Coef. of length variability	Fineness, fiber weight per inch	Mature fibers	Fiber strength
Pounds	Percent of mean 2/	Number 3/	Inches	Percent	Micrograms 4/	Percent	1,000 pounds per sq. in.
- 0.304	- 1.70	+ 1					
- .007	- 0.04		+ 1/32				
- .226	- 1.26			+ 1			
- .756	- 4.23				+ 1		
- .011	- 0.06					+ 1	
+ .179	+ 1.00						+ 1
+ 1.000	+ 5.59	- 3.29	5/	- 4.42	- 1.32	5/	+ 5.59
+ 0.179	+ 1.00	- 0.59	5/	- 0.79	- 0.24	5/	+ 1.00
+ 1.789	+ 10.00	- 5.89	5/	- 7.91	- 2.36	5/	+10.00

1/ As based on the regression coefficients of the six fiber-property equation (1).
2/ As based on 17.89 pounds, the mean strength of this series of tire cord.
3/ An increase of one grade number is equivalent to lowering the grade of the cotton by one step, such as from Strict Middling (grade 4) to Middling (grade 5).
4/ An increase of 1 microgram per inch indicates that the fiber is less fine, or is coarser.
5/ Contribution of this fiber property is too small for such a calculation to have practical meaning.

In regard to upper quartile length and percentage of mature fibers, the contribution from each of these two fiber properties is so small that it would be impractical to cause a 1-pound increase in the strength of 23/5/3 tire cord by a change in either of them. Where an increase in strength of tire cord accompanied an increase in upper quartile length or staple length of raw cotton, as frequently is the case, it is attributable to an associated increase in fiber fineness and in fiber strength rather than to the increase in fiber length per se, as will be explained later.

Data also are shown in table 4 relative to the amount of change in the separate fiber properties necessary to produce 1 percent and 10 percent increases in the mean strength of 23/5/3 tire cord.

The partial coefficient of correlation is considered the most reliable of the available statistical measures for determining the importance of the separate fiber properties, in that it measures how much a particular fiber property reduces the variance in tire-cord strength after the effects of all the other measured fiber properties have been taken into account. Thus, this measure is radically different from that of the simple correlation coefficient, which deals with the effect of a separate fiber property without regard to the effects of any other associated fiber properties. To the extent that certain fiber properties are interrelated, therefore, the simple correlation coefficients are inaccurate and frequently misleading with respect to indicating the importance of any fiber property.

There is a tendency on the part of some to replace the partial correlation coefficient by the beta coefficient, since so much time and effort are required for calculating the former, especially when more than three variables are involved. However, a great deal of accuracy and reliability may be sacrificed with respect to the interpretation of results, if the partial correlation coefficients are not determined.

Referring to table 5, the values for the partial coefficients of correlation indicate that the properties of raw cotton studied in this instance rank in order of importance to the strength of 23/5/3 carded tire cord, as follows:

(1) Fiber strength
(2) Coefficient of length variability
(3) Grade of cotton
(4) Fiber fineness
(5) Percentage of mature fibers
(6) Upper quartile length

Upper quartile length and percentage of mature fibers have been found to give partial correlation coefficients of insignificant values and, insofar as the strength of tire cord is concerned, those two fiber properties appear to be of little or no importance.

Table 5. - Rank of importance of 6 measured cotton fiber properties with respect to strength of 23/5/3 carded tire cord for American upland cottons, crop years 1935-37

(These results are based on partial correlation coefficients obtained from multiple linear correlation analyses of 377 averages of cottons grown in duplicate.)

Rank	Fiber properties	Partial correlation coefficients	Contribution of fiber properties
(1)	Fiber strength, in 1,000 pounds per square inch	+ 0.834 ± 0.016	Significant
(2)	Coefficient of length variability, in percent	- .583 ± .034	do
(3)	Grade of cotton, by number	- .314 ± .046	do
(4)	Fiber fineness, micrograms per inch	- .283 ± .047	do
(5)	Percent of mature fibers	- .062 ± .051	Negligible 1/
(6)	Upper quartile length, in inches	- .021 ± .051	do

1/ Coefficient of partial correlation is so small in relation to its standard error that the effect of this fiber property is considered statistically insignificant.

In the light of their respective standard errors, as also shown in table 5, it is evident that the partial correlation coefficients for fiber strength, length variability, grade, and fineness in relation to tire-cord strength are significant and not due to chance alone. The partial correlation coefficient obtained for fiber strength is, as a matter of fact, the highest that this series of studies has yielded to date.

With respect to percentage of mature fibers and upper quartile length, however, it must be concluded that these two fiber properties produce little or no effect on tire-cord strength. In the case of upper quartile length, the standard error is more than twice as large as the partial correlation coefficient and, with mature fibers, the standard error is almost as large as the partial coefficient.

Although length as a specific fiber property has been found to exert no detectable effect on tire-cord strength, it should be noted that the strength of tire cord does increase more or less with increase in staple length or upper quartile length of raw cotton. The explanation for this seemingly inconsistent observation is the fact that fiber length and fiber-weight fineness are significantly correlated and that fiber-weight fineness and fiber strength are significantly correlated, as shown by the partial coefficients of correlation reported in the previous study 9/. Thus, in a general and practical way, fiber length may be used as an indirect basis for getting fiber fineness and, to a lesser extent, fiber strength and percentage of mature fibers. Therefore, as an indicator of fiber fineness and fiber strength in the absence of measurements and standards for fiber fineness and fiber strength, fiber length and staple length standards assume importance in connection with the production of strength in tire cord, even though fiber length itself exerts a negligible effect to this end.

Although the simple coefficients of correlation indicate only the apparent importance of the separate fiber properties to tire-cord strength, and the partial coefficients of correlation refer to their actual importance of the fiber properties in this respect, it is of interest to note the ranks of importance given to the fiber properties by these two different sets of statistical values, as follows:

(Rank)	Based on partial correlation	Based on simple correlation
(1)	Fiber strength	Fiber strength
(2)	Coef. length variability	Fiber fineness
(3)	Grade of cotton	Coef. length variability
(4)	Fiber fineness	Grade of cotton
(5)	Percentage mature fibers 1/	Upper quartile length
(6)	Upper quartile length 1/	Percentage mature fibers 1/

1/ Coefficient of correlation, being less than three times its standard error, is statistically insignificant.

9/ See footnote 1/, p. 6.

RELATIONSHIPS BETWEEN TIRE-CORD ELONGATION AT THE 10-POUND LOAD AND VARIOUS COMBINATIONS OF FIBER PROPERTIES

The percentage of elongation at the 10-pound load and at the point of rupture for the 23/5/3 carded tire cord manufactured from each of the 754 lots of cotton was obtained from autographic charts made in connection with the tire-cord strength tests, as previously described. At the 10-pound load, the elongation for this series of tire cord averaged 11.34 percent and ranged from 7.73 to 14.58 percent. The elongation at the point of rupture averaged 16.01 percent and ranged from 11.90 to 20.40 percent. Thus, the values for the mean tire-cord elongation and for the range of elongation are somewhat greater at the point of rupture than at the 10-pound load.

Studies have been made of the multiple linear and curvilinear correlation between the six fiber properties and each of the two types of tire-cord elongation. Studies also have been made of various combinations of less than six fiber properties in relation to both measures of tire-cord elongation, as well as of the simple correlation between such tire-cord elongation and each fiber property.

Two companionate series of regression equations and sets of statistical values have been developed; 17 for the relationships between the fiber properties and tire-cord elongation at the 10-pound load and 21 for those concerning the elongation at the point of tire-cord rupture. Only a few of the equations in reference to the former, however, are included in this paper, as shown in the graphic charts of figures 13 to 20; none of the equations pertaining to tire-cord elongation at the point of rupture are presented. This incomplete and less detailed method of treatment is considered adequate in this report, in view of the fact that the correlation between the fiber properties and each of the elongation measures is so small, that both sets of results are similar in a number of particulars, and that the percentage of elongation at the 10-pound load is the measure more generally used in commercial practice. 10/

Referring to equation (28), as shown in figure 13, it will be seen that the multiple linear coefficient of correlation for the relationship between the percentage of tire-cord elongation at the 10-pound load and the six fiber properties considered is 0.679. The coefficient of determination is 0.461, indicating that only 46 percent of the variance in this tire-cord elongation is accounted for by these six fiber properties.

In view of the fact that such a low multiple correlation coefficient was found, it was thought possible that curvilinear correlation might be present and the explanation of the low value obtained. However, on plotting the residuals of the six fiber-property equation off the net regression lines for each fiber property, there was no indication of a curvilinear relationship for any of the fiber properties.

10/ If any of the equations omitted in reference to tire-cord elongation are needed, or if more detailed information is desired on the relationships involved in this phase, such material as is available will be supplied on request.

The low coefficient of correlation obtained with the six fiber-property equation, therefore, is taken to mean that elongation of such tire cord is due either to some one or more fiber properties not considered in these statistical analyses - as fiber elongation and fiber elasticity - or else that elongation is more a function of the construction of tire cords than it is of fiber properties. Experimental evidence beyond the scope of this study, however, is needed for a more precise and final conclusion.

The standard error of the six fiber-property equation (28) is $\pm$ 0.95, which indicates that two-thirds of the estimated percentages of elongation at the 10-pound load, as based on this equation, would be expected to be within this range of the actual percentage of elongation. This compares with $\pm$ 1.11 percentage of elongation when the best one fiber-property equation is used, namely fiber strength, and with $\pm$ 1.29 percentage of elongation when the estimate is taken as the mean value of the 377 observations without the consideration of any fiber property.

Six equations have been derived involving five fiber properties, each of the six fiber properties being omitted in turn. Four of the equations, namely those in which grade, upper quartile length, coefficient of length variability, and percentage of mature fibers are omitted in turn, give practically as good estimates for cord elongation as does the six fiber-property equation (28). This indicates that the four fiber properties mentioned are of practically no importance, insofar as their effect on tire-cord elongation at the 10-pound load is concerned, and that the tests for these four fiber properties may be omitted without any appreciable loss in accuracy of estimated elongation. The length array test, however, would have to be made, if fiber fineness is used in the equation.

The other two equations involving five fiber properties in which fiber fineness and fiber strength are omitted in turn, indicate that fiber strength is of considerable importance to the elongation of 23/5/3 tire cord at the 10-pound load, and that fiber fineness is of some importance. More particularly, when fiber strength is omitted from the six fiber-property equation (28), the standard error is increased from $\pm$ 0.95 to $\pm$ 1.22 and when fiber fineness is omitted, the standard error is increased from $\pm$ 0.95 to $\pm$ 1.00.

Another way to judge the relative importance of the two significantly contributing fiber properties to tire-cord elongation at the 10-pound load is to compare the respective coefficients of determination with that obtained when all six fiber properties are included in the equation. When all six of the fiber properties are used, the coefficient of determination indicates that 46 percent of such tire-cord elongation variance is accounted for, whereas, when fiber strength is omitted, only 10 percent of the cord-elongation variance is accounted for by the remaining five fiber properties. And, when fiber fineness is omitted, the other five fiber properties account for only 40 percent of the variance in the tire-cord elongation.

It is interesting to note the statistical values found for the correlation between the two fiber properties of fiber strength and fiber fineness with tire-cord elongation at the 10-pound load, as shown by equation (36), listed in figure 14. With only these two fiber properties, the correlation coefficient is almost as high as that found for all six fiber properties, the figures being 0.671 and 0.679, respectively. The corresponding coefficients of determination are 0.450 and 0.461, indicating that only 1 percent more of the variance in the tire-cord elongation at the 10-pound load is accounted for by the inclusion in the equation of the four omitted fiber properties, namely, grade of cotton, upper quartile length, coefficient of length variability, and percentage of mature fibers. In other words, practically as good an estimate of the percentage of tire-cord elongation may be expected from using equation (36) involving only fiber fineness and fiber strength as from equation (28) including all six fiber properties.

RELATIONSHIPS BETWEEN TIRE-CORD ELONGATION AT THE 10-POUND LOAD AND SEPARATE FIBER PROPERTIES

Results from studies of simple correlation between each of the six fiber properties and the percentage of elongation at the 10-pound load, equations of which are listed in figures 15 to 20, reveal that the only fiber property showing significant correlation is that of fiber tensile strength. The correlation coefficients with the other fiber properties and tire-cord elongation are low, being less than 0.400 in every case.

Equation (39), figure 15, representing the relation between elongation at the 10-pound load and fiber strength, shows that its precision is better than that obtained from the equation for the remaining five fiber properties in combination. The coefficients of determination indicate that 26 percent of the variance in tire-cord elongation at the 10-pound load is accounted for by fiber strength alone, whereas only 10 percent is accounted for by the remaining five fiber properties in combination.

In general, none of the separate fiber properties possesses much merit for estimating the percentage of tire-cord elongation at the 10-pound load. This is evident on the basis of the standard error of the best separate fiber property equation (39) and that of a single observation of the mean of the 377 observations, namely $\pm$ 1.29. Thus, without knowledge of any fiber property or even without making any tests for elongation, one could estimate the percentage of elongation as being 11.34, or the mean of the series, and expect to be correct within $\pm$ 1.29 of this value in two-thirds of the cases. This, of course, assumes that cottons having similar ranges and distributions of fiber properties are being considered. When strength of fiber alone is used for estimating the percentage of elongation, the standard error is $\pm$ 1.11, which indicates that in two-thirds of the cases one could estimate within this range of elongation.

IMPORTANCE OF EACH FIBER PROPERTY TO TIRE-CORD ELONGATION AT THE 10-POUND LOAD

On the basis of the regression coefficients of the six fiber-property equation (28), calculations have been made as to the effect on tire-cord elongation at the 10-pound load from unit changes in each fiber property, and as to the amount of changes in the fiber properties necessary to produce a unit change in tire-cord elongation as well as a change equivalent to 10 percent of the mean percentage of cord elongation. The results obtained show that practical changes in fiber properties of only fineness and strength cause appreciable changes in percentage of tire-cord elongation at the 10-pound load. Assuming that the magnitudes of all other fiber properties remain the same, it is possible to draw the following conclusions:

> An increase of 1 microgram per inch in fiber fineness, decreases the percentage of tire-cord elongation at the 10-pound load by 1.07 (the coarser the fiber, the less the elongation); and
>
> An increase of 1,000 pounds per square inch in fiber strength decreases the percentage of cord elongation by 0.12.

Expressed on the basis of the amount of change necessary in a fiber property to produce a unit change in percentage of tire-cord elongation at the 10-pound load, shows the following:

> A decrease of 0.93 microgram per inch in fiber fineness increases the percentage of cord elongation by 1.00 (the finer the fiber, the greater the elongation); and
>
> A decrease in fiber strength of 8,470 pounds per square inch increases the percentage of cord elongation by 1.00.

The contribution of grade, of upper quartile length, of coefficient of length variability, and of percentage of mature fibers is too small for such calculations, as referred to above, to have practical meaning.

The values for the partial coefficients of correlation for each fiber property in relation to tire-cord elongation at the 10-pound load are shown in table 6. These coefficients, by their magnitudes, indicate the relative importance of each fiber property to this tire-cord property after the effects of all other measured fiber properties have been accounted for. These measures differ from the simple correlation coefficient where the effect of the other fiber properties are ignored, at least, in the sense that they are not considered in the correlation analysis. The effect of other fiber properties, however, are always present, in that

Table 6. - Rank of importance of 6 measured cotton fiber properties with respect to percentage of elongation of 23/5/3 carded tire cord at the 10-pound load for American upland cottons, crop years 1935-37

(These results are based on partial correlation coefficients obtained from multiple linear correlation analyses of 377 averages of cottons grown in duplicate.)

Rank	Fiber properties	Partial correlation coefficients	Contribution of fiber properties
(1)	Fiber strength, in 1,000 pounds per square inch	-0.632 ± 0.031	Significant
(2)	Fiber fineness, micrograms per inch	$-.324 \pm .046$	do
(3)	Percent of mature fibers	$+.112 \pm .051$	Negligible 1/
(4)	Grade of cotton, by number	$-.040 \pm .051$	do
(5)	Coefficient of length variability, in percent	$+.029 \pm .051$	do
(6)	Upper quartile length, in inches	$+.016 \pm .051$	do

1/ Coefficient of partial correlation is so small in relation to its standard error that the effect of this fiber property is considered statistically insignificant.

they have influenced the magnitude of the dependent variable - tire-cord elongation in this case. More complete information on these two statistical measures is contained in the previous report. 11/

According to the partial correlation coefficients, fiber strength and fiber fineness are the only two fiber properties of those considered that exert a significant effect on the percentage of tire-cord elongation at the 10-pound load, fiber strength ranking first in this respect and fiber fineness, second. The most interesting finding perhaps is that with respect to upper quartile length which, as in the case of tire-cord strength, is apparently the least important fiber property to tire-cord elongation at the 10-pound load of the six which have been considered. It frequently happens, however, that in order to obtain cottons of the desired strength and fineness, it is necessary to obtain cotton of longer length; but this is not always necessary, as can be readily seen by reference to the correlations between different pairs of fiber properties, as the earlier report shows. 12/

Remembering that the partial coefficient of correlation refers to the actual contribution of each fiber property and that the simple correlation coefficient indicates only the apparent contribution, as explained previously in the case of tire-cord strength, the ranks of importance given to the separate fiber properties for tire-cord elongation at the 10-pound load by the two different sets of statistical values are of interest, as follows:

Rank	Based on partial correlation	Based on simple correlation
(1)	Fiber strength	Fiber strength
(2)	Fiber fineness	Upper quartile length
(3)	Percentage mature fibers 1/	Fiber fineness
(4)	Grade 1/	Coef. length variability 1/
(5)	Coef. length variability 1/	Grade 1/
(6)	Upper quartile length 1/	Percentage of mature fibers 1/

1/ Coefficient of correlation, being less than three times its standard error, is statistically insignificant.

RELATIONSHIPS BETWEEN TIRE-CORD ELONGATION AT POINT OF RUPTURE AND VARIOUS COMBINATIONS OF FIBER PROPERTIES

The low correlation found with respect to the combined effect of the six fiber properties and the percentage of elongation at the 10-pound load suggested the possibility of curvilinear correlation. However, since no curvilinear correlation was found, it was thought that perhaps the low

11/ See footnote 1/, p. 6.

12/ See footnote 1/, p. 6

correlation might have resulted from the elongation, observed at the 10-pound load, being too close to the point of rupture in the case of weak tire cords and too far from the point of rupture in the case of strong tire cords. It was further thought that the percentage of elongation at the point of rupture might be a better basis for measuring this manufacturing property in connection with studies of the effect of fiber properties on elongation. This percentage of elongation is obtained by dividing the total stretch of the test specimen at the point of rupture by the original 10-inch length of the test specimen, and multiplying the quotient by 100. Readings were made from the same strength-elongation charts as were used in the case of the previous studies on the elongation at the 10-pound load.

A similar procedure was followed in correlating the fiber properties with the percentage of tire-cord elongation at the point of rupture as for the tire-cord elongation at the 10-pound load. Twenty-one equations were developed that involved separate and various combinations of fiber properties; but they are not presented in this paper, since the over-all correlation was found to be no higher with the percentage of elongation at the point of rupture than with that at the 10-pound load, and since the percentage of elongation at the 10-pound load appears to be the measure more commonly used in the commercial testing of tire cord. The more outstanding findings obtained from these studies, however, will be discussed in their relation to corresponding results developed in connection with tire-cord elongation at the 10-pound load.

A multiple correlation coefficient of 0.665 was obtained for the relation between the percentage of tire-cord elongation at the point of rupture and the six fiber properties in combination. This compares with 0.679 for the corresponding equation relating to the elongation at the 10-pound load. The respective coefficients of determination indicate that 44 percent of the variance in tire-cord elongation at the point of rupture is explained by the six fiber properties, whereas 46 percent is explained in the case of elongation at the 10-pound load. The low correlation coefficient with respect to elongation at the point of rupture suggested the possibility of curvilinear correlation. However, no indication of such a relationship was found when curvilinear correlation studies were made of the data.

Six equations, involving five fiber properties, were developed, where each fiber property was omitted in turn. The statistical values, when compared with those for the six fiber-property equation, show that strength and fineness of the fiber properties under consideration have the greatest effect on tire-cord elongation at the point of rupture. These results are similar to those found with respect to tire cord elongation at the 10-pound load.

Of the equations developed for different pairs of fiber properties, the best result was obtained with fiber fineness and fiber strength. The degree of relationship between tire-cord elongation at the point of rupture and these two fiber properties is indicated by a coefficient of correlation of 0.564, as compared with 0.665 when all six fiber properties are involved. These values are relatively small and, when squared, indicate

that only 32 percent of the total variance in the percentage of tire-cord elongation at the point of rupture is explained by fiber strength and fiber fineness, as compared with 44 percent for all six fiber properties.

RELATIONSHIPS BETWEEN TIRE-CORD ELONGATION AT THE POINT OF RUPTURE AND SEPARATE FIBER PROPERTIES

None of the simple correlations between the percentage of tire-cord elongation at the point of rupture and the six separate fiber properties are sufficiently high to place much reliance upon the correlations, the coefficients being less than 0.500 in all cases. Four of the correlation coefficients, however, are statistically significant, being greater than three times their standard errors and indicating that the correlations are not due to chance alone. In order of rank, they are: Upper quartile length, fineness, strength, and grade of cotton. As previously pointed out, such correlations are only apparent, since they refer to correlations where the effects of other associated fiber properties on the relationship have been ignored. Therefore, different ranks of importance for the separate fiber properties in relation to tire-cord elongation at the point of rupture are obtained when the results are based on net regression and partial correlation coefficients, and when the effects of other interrelated fiber properties are taken into account. This will be reported in the next section.

IMPORTANCE OF EACH FIBER PROPERTY TO TIRE-CORD ELONGATION AT THE POINT OF RUPTURE

Based on the regression coefficients of the six fiber property equation, calculations have been made as to the effect of unit changes of each fiber property on the percentage of elongation at the point of rupture, the effect of unit changes of each fiber property in terms of the percentage of the mean value for the percentage of elongation, and the amount of change in each fiber property necessary to produce a change equivalent to 10 percent of the mean percentage of elongation. The two latter methods of expression are of assistance in comparing the findings with those in connection with the elongation at the 10-pound load.

On the assumption that the magnitudes of all the other fiber properties remain the same, the following significant changes in the percentage of tire-cord elongation at the point of rupture result from changes in each fiber property:

Lowering the grade of the cotton by one step decreases the percentage of elongation by 0.26;

An increase of 1 percent in the coefficient of length variability reduces the percentage of elongation by 0.10;

An increase of 1 microgram per inch in fiber weight decreases the percentage of elongation by 1.80 (the coarser the fiber, the less the elongation); and

An increase of 1,000 pounds per square inch in fiber strength decreases the percentage of tire-cord elongation by 0.11.

Expressing the above relationships in another way, it is found that an increase of one unit in the percentage of elongation is obtained by --

Raising the grade of the cotton by 4 steps; or

Decreasing the coefficient of length variability by 10 percent; or

Decreasing the fiber weight per inch by 0.55 microgram (the finer the fiber, the greater the elongation); or

Decreasing the fiber strength by 9,000 pounds per square inch.

The contribution of upper quartile length and of percentage of mature fibers is too small for such calculations as the above to have practical meaning.

According to the partial correlation coefficients reported in table 7, strength is the most important fiber property influencing the elongation at the point of rupture. Next in order are the fiber properties of fineness, coefficient of length variability, and grade. The percentage of mature fibers and upper quartile length have negligible effects upon the variance in the percentage of tire-cord elongation.

The partial correlation coefficients reveal a radically different picture from that furnished by the simple correlation coefficients. For purposes of comparison, the importance of the various fiber properties as measured by the two sets of correlation coefficients are listed as follows:

Rank	Based on partial correlation	Based on simple correlation
(1)	Fiber strength	Upper quartile length
(2)	Fiber fineness	Fiber fineness
(3)	Coef. of length variability	Fiber strength
(4)	Grade of cotton	Grade of cotton
(5)	Percentage of mature fibers 1/	Coef. length variability 1/
(6)	Upper quartile length 1/	Percentage of mature fibers 1/

1/ The correlation coefficient, being less than three times its standard error, is considered statistically insignificant.

The most outstanding observation is the low rank of upper quartile length, based on the partial correlation coefficient, as compared with that based on the simple correlation coefficient. If one were to judge the importance of the fiber properties with respect to elongation on the basis of the simple correlation coefficient alone, upper quartile length would be considered the most important fiber property.

Table 7. - Rank of importance of 6 measured cotton fiber properties with respect to percentage of elongation of 23/5/3 carded tire cord at the point of rupture for American upland cottons, crop years 1935-37

(These results are based on partial correlation coefficients obtained from multiple linear correlation analyses of 377 averages of cottons grown in duplicate.)

Rank	Fiber properties	Partial correlation coefficients	Contribution of fiber properties
(1)	Fiber strength, in 1,000 pounds per square inch	-0.499 ± 0.039	Significant
(2)	Fiber fineness, micrograms per inch	$-.398 \pm .043$	do
(3)	Coefficient of length variability, in percent	$-.201 \pm .049$	do
(4)	Grade of cotton, by number	$-.171 \pm .050$	do
(5)	Percent of mature fibers	$+.042 \pm .051$	Negligible 1/
(6)	Upper quartile length, in inches	$+.027 \pm .051$	do

1/ Coefficient of partial correlation is so small in relation to its standard error that the effect of this fiber property is considered statistically insignificant.

The partial correlation coefficient, however, clearly shows that upper quartile length has practically no effect on tire-cord elongation. It is only because fiber length is correlated with other contributing fiber properties that it can be used to represent them and, therefore, show a significant correlation when so used in simple correlation analyses. Accordingly, fiber length per se is not the controlling factor. Care must be used continuously, as repeatedly pointed out in this report, if conclusions are to be drawn from simple correlation coefficients alone.

RELATIONSHIPS BETWEEN THREE PAIRS OF TIRE-CORD PROPERTIES, AND BETWEEN EACH OF THOSE PROPERTIES AND THE STRENGTH OF SINGLES YARN

The question arises as to what correlation, if any, exists between the two elongation measures for 23/5/3 tire cord. The answer is graphically revealed by the scatter diagram shown in figure 21. Correlation analysis of the data indicates a fairly high positive correlation between the two sets of measurements, the coefficient of simple correlation being + 0.871. The scatter about the regression line, however, indicates that the two expressions of tire-cord elongation are not precisely related, otherwise all the dots would have fallen on a straight or curved line.

When the percentage of 23/5/3 tire-cord elongation at the 10-pound load, is plotted against tire-cord strength, a negative correlation is indicated, as illustrated by figure 22. The coefficient of correlation is -0.378 ± 0.44, which, although small, is statistically significant. The negative correlation indicates that the stronger the cord, the less is the elongation. More particularly, as based on this analysis, each increase of 1 percent in tire-cord elongation at the 10-pound load is associated with a reduction of 0.58 pound in tire-cord strength.

On the other hand, when the elongation of this tire cord at the point of rupture is plotted against tire-cord strength (see fig. 23), a positive but insignificant correlation is indicated. The correlation coefficient is only $+ 0.069 \pm 0.051$. In this case, each increase of 1 percent in tire-cord elongation at the point of rupture is associated with an increase of only 0.08 pound in tire-cord strength.

The values previously reported are based on tire-cord strength being the dependent variable in both cases. However, when the percentage of elongation is made the dependent variable, an increase of 1 pound in 23/5/3 tire cord strength is associated with a decrease of 0.25 in the percentage of elongation at the 10-pound load, and an increase of 1 pound in the strength of such cord is associated with an increase of 0.06 in the percentage of elongation at the point of rupture. According to the latter figure, obviously a relatively great change in tire cord strength would be necessary to affect significantly the percentage of elongation at the point of rupture.

In the manufacture of tire cord, it is important to know in advance whether certain specifications with respect to strength of tire cord can be realized before processing large quantities of single yarns into the

cords. Correlation between the strength of 23/5/3 carded tire cord and the converted skein strength of 23s carded yarn 13/, spun from corresponding cottons with optimum twist multipliers in relation to the staple length of the raw cottons, reveal that such estimates can be made with a fair degree of precision. The estimating equation is found to be --

$$X'_{23} = + 0.123\ X_{36} + 6.74$$

Where X'_{23} represents the estimated strength of 23/5/3 tire cord, in pounds, and

X_{36} represents the strength of 23s yarn, in pounds per skein.

This equation indicates that an increase of 1 pound in the strength of 23s yarn increases the strength of 23/5/3 tire cord by 0.123 pound or by approximately 1/8 pound. The standard error of estimate for this equation is $\pm$ 0.87 pound, which means that the estimated strengths of such tire cord would be expected to fall within this range of the actual values in two-thirds of the cases. The coefficient of correlation between this tire cord and yarn strength is + 0.897, indicating a relatively high positive correlation between cord strength and yarn strength. The coefficient of determination is 0.805, thus signifying that 80 percent of the variance in the strength of this tire cord is explained by yarn strength. A graphical presentation of the relationship between tire-cord strength and yarn skein strength is given in figure 24.

What, if any, relationship exists between the percentage of 23/5/3 tire-cord elongation and the strength of 23s single yarn? Correlation analysis reveals an insignificant negative correlation between tire-cord elongation at the 10-pound load and the converted strength of 23s carded yarn spun from corresponding cottons with optimum twist in relation to the staple length of the raw cottons. The coefficient is only - 0.142, $\pm$ 0.050. A positive correlation, however, has been found between the percentage of tire-cord elongation at the point of rupture and the converted strength of such 23s yarn. In this case the coefficient, + 0.295 $\pm$ 0.047, while comparatively small, is statistically significant. The elongation of tire cord at the 10-pound load and the elongation of tire cord at the point of rupture, in relation to the strength of 23s yarn, are shown graphically in figures 25 and 26.

APPLICATION OF THE EQUATIONS

Sixty-four equations have been developed in connection with this study: 26 for estimating from fiber data the strength of 23/5/3 tire cord; 17 for tire-cord elongation at the 10-pound load, and 21 for cord elongation at the point of rupture. Twenty-three equations are presented in table 2

13/ The strength of 23s yarn was converted from the strength of 22s yarn by the method described in "An Improved Method for Converting Skein Strength of Cotton Yarn to the Strength of a Specified Yarn Count," by Malcolm E. Campbell. U.S. Department of Agriculture, Circular No. 413, Oct. 1936.

for tire-cord strength, 3 are presented in the Discussion as special cases, and 8 are shown in figures 13 to 20 for tire-cord elongation at the 10-pound load. The remaining 30 equations are not included in this report, for the reasons previously given, but the statistical findings associated with them have been taken into account.

The fiber-cord-property equations here presented, provide a tool for predicting or estimating the strength of 23/5/3 tire cord and its elongation at the 10-pound load from a knowledge of the magnitude of the various fiber properties. To illustrate the use of these equations, the magnitudes of four of the fiber properties for one of the cottons used in this study are given below:

X_1, grade of cotton, by number........................ 5.00
X_3, coefficient of length variability, in percent....28.00
X_4 fiber fineness, in micrograms per inch............ 4.80
X_6, fiber strength, 1,000 pounds per square inch.....89.00

The values listed above are substituted in the appropriate equation. If the estimated strength of 23/5/3 cord is desired and if four fiber properties are included, equation (8), as shown in table 2, should be used. This equation is as follows:

$$(8)\ X'_{23} = -0.304X_1 - 0.215X_3 - 0.769X_4 + 0.181X_6 + 15.14$$

The values substituted in this equation give the following result:

$$X'_{23} = -0.304\ (5.00) - 0.215\ (28.00) - 0.769\ (4.80) + 0.181\ (89.00) + 15.14000 = 20.0 \text{ pounds}$$

The estimated tire-cord strength of 20.0 pounds, as calculated above, compares with 19.6 pounds for the value obtained by actual test.

The factors and the constant are set up so that five decimal places will result in all the products. This is done so that the calculation may be made by cumulating these products on a calculating machine, then adding or subtracting the constant term according to its sign. In several cases the products are multiplied negatively. Such a procedure represents a considerable saving of time when a large number of estimates are involved.

That a number of more or less radically different tire-cord strength and tire-cord elongation estimating equations with various degrees of reliability can be obtained from analysing the data for a given series of cottons, depending upon which and how many fiber properties are correlated, is fully demonstrated by the evidence presented in table 2 and in the graphic charts which follow. It is felt, however, that the equations presented in this paper possess merit for making comparisons and predictions in reference to tire-cord strength and tire-cord elongation at the 10-pound lead, insofar as American upland cottons and the specified 23/5/3 tire cord are concerned; since they were derived from analyzing such a large number of cottons; since such wide ranges of fiber properties, cord strength and cord elongation were involved; and since such comparable methods and conditions of test were used with all samples.

Estimated values of tire-cord strength and elongation obtained for other American upland cottons by substituting fiber-property values in any of these equations generally should agree with their actual cord strength and elongation values, within the limits of tolerance specified, provided that a number of conditions are satisfactorily met.

Individual cases, no doubt, will occur where the estimated and actual values will differ more than the limits of accuracy indicated. In such event, it is likely that either the equation is being applied to an unusual or extreme cotton (one that is distinctly outside of the range in one or more fiber properties from that from which these equations were developed), or else that the techniques and conditions used by others for measuring fiber and cord properties or for manufacturing cord are appreciably different from those employed in these analyses, or both.

If only an occasional large disparity occurs between the actual and estimated values and if the deviations are sometimes plus and sometimes minus, this would suggest something unusual or extreme about the cotton. On the other hand, if appreciable disparities generally occur and if they are generally either plus or minus, this would indicate that something is unusual or peculiar to the testing or manufacturing phases, or that the tire-cord structure involved is significantly different from that used in these studies and on which the reported equations were developed.

Regardless of any differences in fiber testing techniques or other conditions as between laboratories, the findings from substitutions of the magnitudes of the fiber properties in the equations should result in establishing the proper ranks or relative positions of the various cottons in terms of cord strength. Even though the level of results may vary somewhat between laboratories or from those involved in this study, the ranks obtained should be reasonably reliable, provided that all fiber tests of a kind are made in one and the same laboratory, under one and the same set of conditions, and by the same person or group of persons.

It should be understood, moreover, that the equations reported herein for this series of American upland cottons probably are not applicable to American Egyptian, sea island, and extra long upland cottons, since such growths of cotton have not been included in these studies.

DISCUSSION

One of the most interesting, if not surprising, observations furnished by these correlation analyses is the low rank of importance for upper quartile length in relation to tire-cord strength. This conclusion, however, is borne out by all the different statistical measures of importance that have been used in this study, some of which have not been included in this report. More particularly, as based on partial correlation analyses involving the six fiber properties of equation (1), the partial correlation coefficient for length was found to be only - 0.021, with a standard error of + 0.051, the latter being approximately 2-1/2 times the partial correlation coefficient itself. These figures reveal

the fact that, with this series of American upland cottons, there is no significant correlation between upper quartile fiber length and tire-cord strength. Moreover, the regression coefficient obtained for length in the six fiber-property equation (1) is - 0.225, which means that, when expressed in practical terms, an increase of 1/32 inch in upper quartile length changes the cord strength by only - 0.007 pound, as shown in table 4. This finding, together with the large standard error associated with the regression coefficient, indicates that the effect of upper quartile length on cord strength is practically negligible.

The variable results obtained as to the precise effect of fiber length and its generally insignificant contribution towards the strength of tire cord are interpreted as being attributable to the interactions which occur between the various fiber properties. That such interactions exist can readily be deduced by referring to table 2, which summarizes the 23 regression equations involving one or more fiber properties. Here, it is seen that in six cases, namely with equations (4), (5), (6), (10), (15), and (21), positive regression coefficients occur for upper quartile length. Only four of these coefficients, however, are of any appreciable magnitude. On the other hand, negative regression coefficients occur in three cases, namely, with equations (1), (3), and (7). Of these, only that for equation (7) is of appreciable magnitude. These length regression coefficients vary in both magnitude and sign, because of the number and nature of their associated properties.

The explanation for the apparent differences and discrepancies, referred to above, lies in the interplay or interactions occurring between the various fiber properties. For example, where two fiber properties are correlated with each other and one is omitted in a statistical analysis, there is a tendency for the effect of the omitted fiber property to be taken care of by the fiber property retained. This is particularly true in the case of fiber length and fineness. Since a fiber property is often correlated to some extent with several others 14/, the omission of a fiber property from an analysis frequently affects the magnitudes of several of the regression coefficients for the other fiber properties and may even affect the sign of such regression coefficients.

It is of interest to note that, on the basis of their respective magnitudes, the most variable of the regression coefficients reported are upper quartile length and fiber fineness and that the most constant ones are identified with length variability and fiber strength. The stability of their regression coefficients indicate that the two latter fiber properties are less definitely associated with any of the other fiber properties considered. On the other hand, since fiber length and fineness are fairly highly correlated, when both of these fiber properties are involved in the six fiber-property equation (1), the respective contribution of length and fineness towards the strength of the tire cord is divided between them.

14/ See footnote 1/, p. 6.

Fiber fineness apparently contributes greatly and the negative regression coefficient for length may be taken as an offset. In other words, the two fiber properties should be considered as acting together under such circumstances. However, when fiber fineness is omitted from the statistical analysis, as in equation (4) involving five fiber properties, the contribution of fineness is apparently borne by length with which it is correlated. Thus, on the basis of equation (4), it appears that an increase of 1/32 inch in upper quartile length increases the cord strength by 0.07 pound. This increase, though small, is positive as compared with the negative and insignificant 0.007 pound change based on equation (1), where all six fiber properties are involved. When length is omitted from the analysis, as in equation (2), much less change occurs in the regression coefficient for fineness than when equation (1) is used, in which case all six fiber properties are included. However, when fiber strength is omitted from the analysis, as in equation (7), both length and fineness assume highly significant roles, particularly length in a negative direction.

The foregoing observations lead to the conclusion that regression coefficients with respect to cotton fiber quality, or to any commodity or problem for that matter, are often highly deceiving, particularly if they are not carefully considered in connection with the number of fiber properties or independent variables involved, with the magnitude of the constant term of the equation, and with the nature and extent of the interrelations and interactions that occur between the various fiber properties or independent variables. Obviously, therefore, almost any conclusion within a considerable range may be drawn, the conclusion depending on the number and nature of the variables used in the analysis. In this connection, it is of interest to note that, when the constant term is large and positive, the regression coefficients tend to be relatively large and negative in order that the estimates may be within the range of the actual values. The size of the constant term, however, is not an independent or haphazard quantity; on the contrary, it is dependent upon the magnitudes and algebraic signs of the regression coefficients as well as the mean values of the fiber properties or independent variables involved in the equation. In other words, the constant term and the regression coefficients are interrelated and not independent of each other.

In view of the fact that so many different regression coefficients were found for upper quartile length, some positive and others negative, further studies have been made of the effect of this fiber property by analyzing the 25 shortest cottons, the 25 longest cottons, and the 30 cottons having more or less the same fiber strengths, namely 79 to 80 thousand pounds per square inch. Thus, the range and frequency of the magnitudes of the fiber properties and cord strengths varied for the three series of cottons when compared with each other and with the 377 duplicate lots of cotton included in the entire series. The resulting equations, together with equation (1), are as follows:

S

$$(1)\quad X'_{23} = 16.55-.304X_1-.225X_2-.226X_3-.756X_4-.011X_{35}+.179X_6 \qquad \pm .78$$

$$(25)\quad X'_{23} = 5.75-.409X_1+6.505X_2-.170X_3-.409X_4-.032X_{35}+.223X_6 \qquad \pm .61$$

$$(26)\quad X'_{23} = 17.59-.128X_1-1.467X_2-.323X_3-.580X_4+.011X_{35}+.183X_6 \qquad \pm .59$$

$$(27)\quad X'_{23} = 31.73-.334X_1-.515X_2-.183X_3-1.341X_4+.069X_{35}-.057X_6 \qquad \pm .75$$

Equation (1) is for the 377 lots of cottons, including all lengths and strengths; equation (25) represents the 25 shortest cottons; equation (26) refers to the 25 longest cottons, and equation (27) relates to the 30 cottons having fiber strengths of 79 and 80 thousand pounds per square inch.

The results derived from correlating tire cord strength with the six fiber properties indicate that, for the 25 shortest cottons, upper quartile length has a positive and significant effect on cord strength. In the case of the longest cottons, however, the effect of upper quartile length on cord strength is small, more or less insignificant, and negative. For example, an increase of 1/32 inch in the case of the group of short cottons increases the cord strength by 0.20 pound, whereas an increase of 1/32 inch in the case of the group of long cottons decreases the cord strength by 0.05 pound, a negligible amount. The two equations differ considerably from each other with respect to the constant terms and the regression coefficients for grade, upper quartile length, and length variability.

In equation (27), derived from analyzing 30 cottons having fiber strengths of 79 or 80 thousand pounds per square inch, it is found that changes in cord strength naturally are the result of differences in the fiber properties other than strength, since fiber strength was held practically constant and thus had little or no opportunity to influence the cord strength, except as to its effect upon the level of the results or on the magnitude of the constant term. The most interesting facts revealed by this equation, aside from its confirmation of the lack of effect of fiber strength on cord strength under the condition imposed, is the large increase in the magnitude of the constant term, the small regression coefficient for the effect of upper quartile length, and the unusually large regression coefficient for the contribution of fiber fineness towards tire-cord strength.

On a basis of the coefficients of multiple determination, appreciably different amounts of total variance in the cord strength of the several series of selected cottons are accounted for by the six fiber properties considered. With the 25 shortest cottons, 79 percent of the total cord-strength variance is explainable; with the 25 longest cottons, 90 percent; and with the 30 cottons having a more or less constant fiber tehsile strength, only 65 percent. These amounts of explainable tire-cord-strength variance compare with 85 percent for the entire series of 377 duplicate cottons, including cottons of all lengths and strengths.

The foregoing results emphasize how important it is to have, for studies of this kind, representative samples covering wide ranges of fiber properties; also, how important it is when conclusions are made with respect to the importance of various fiber properties that such statements be qualified by making clear that they refer to cottons of definite ranges and distributions of fiber properties and that they hold only for the number and nature of the fiber properties used in the analyses.

The 25 shortest cottons referred to in equation (25) gave a mean tire-cord strength of 16.08 pounds and the 25 longest cottons represented by equation (26) furnished a mean tire-cord strength of 19.47 pounds, or a difference of 3.39 pounds between the mean tire-cord strengths of the two groups of cottons. This difference is appreciable, constituting 19 percent of the mean tire-cord strength of the entire series of 377 cottons (17.89 pounds).

The mean upper quartile length of the 25 shortest cottons is 0.842 inch and that of the 25 longest cottons is 1.346 inches, or a difference of 0.504 inches in the mean upper quartile lengths between the two groups of cotton. Expressed in the conventional units of measure used in the cotton trade, the difference in length between the two groups of cottons amounts to 16/32 inch or 1/2 inch. This is a relatively large length difference insofar as cotton is concerned. Now, in the light of this large fiber length difference, it would appear that length of fiber itself is important to the strength of tire cord; that the factor of fiber length alone should explain most, if not all, of this difference in tire-cord strength; and that the statistical data previously presented in this paper to the effect that fiber length is unimportant to tire-cord strength are in error.

More particularly, on a basis of the figures cited above, it would appear that, on the average, an increase of 1/32 inch in upper quartile length causes an increase of 0.20 pound in tire-cord strength. This is not the case, however, as the mean values for the other fiber properties measured also differ appreciably between the two groups of cottons under consideration. Furthermore, according to the statistical findings previously presented, the effects of the combined differences in the other fiber properties associated with the cottons of the two widely different length groups explain almost the entire difference in tire-cord strength found to exist between them.

For convenience in following these comparisons and this discussion, the mean values for the measured fiber properties and for tire-cord strength are listed in table 8 for the 25 shortest and for the 25 longest cottons, together with corresponding values for the 30 cottons possessing more or less constant and average fiber strength (79,000 to 80,000 pounds per square inch) as well as for the entire series of 377 lots of cotton. As compared with the values for the 25 shortest cottons, it is evident that the 25 longest cottons are, on the average, 0.4 of a step higher in grade; 0.3 percent more uniform in fiber length; finer by 2.03 micrograms per inch in fiber weight; 5.7 percent less in mature fibers; and stronger by 6,900 pounds per square inch.

Table 8. - Mean values for strength of 23/5/3 carded tire cord, and for 6 measured cotton fiber properties representing selected groups of American upland cottons, as compared with corresponding values for the entire series of 377 cottons grown in duplicate, crop years 1935-37

Properties	Mean values for			
	25 shortest cottons	25 longest cottons	30 cottons, fiber strength 79-80,000 lbs. per square inch	377 cottons, entire series
Tire-cord strength, in pounds	16.08	19.47	18.17	17.89
Grade of cotton, by number	6.5	6.1	6.0	6.2
Upper quartile length, in inches	0.842	1.346	1.091	1.087
Coef. of length variability, in percent	29.0	28.7	28.0	28.2
Fiber fineness, micrograms per inch	5.63	3.60	4.72	4.74
Percent of mature fibers	71.9	66.2	72.2	72.3
Fiber strength, in 1,000 lbs. per sq. inch	76.5	83.4	79.6	79.5

On the basis of the effect of a unit change in each measured fiber property on the strength of tire cord, as shown in table 4, differences in the average fiber properties (other than length) of the 25 shortest and the 25 longest cottons account for differences in cord strength, as follows:

Fiber properties	Tire-cord strength, lbs.
Fineness	1.53
Strength	1.24
Grade	0.12
Coef. of length variability	0.07
Maturity	0.06
Total	3.02

The 25 longest cottons gave tire cords which averaged 3.39 pounds stronger than did the 25 shortest cottons. Mean differences between the 5 respective fiber properties of the two groups of cottons, as shown above, account for 3.02 pounds. This leaves a difference of only 0.37 pound in tire-cord strength between the two groups of cottons, or 11 percent, that is unexplainable and presumably due to fiber properties other than those considered in this study. Thus, it is evident how cottons of longer staple length can give stronger tire cord than do shorter cottons; how the fiber properties associated with fiber length can explain such differences in tire-cord strength; and how fiber length as a property, by itself, does not exert any significant effect on tire-cord strength.

The data and comparisons referred to above emphasize the uncertainties and errors that arise when interpretations and conclusions are attempted with respect to tire-cord strength, or even yarn strength, on the basis of fiber length alone or of any separate fiber property, when significant interrelationships exist between the fiber properties, as they generally do in the case of cotton. Although an increase in cotton fiber length has not been found to exert any appreciable effect on tire-cord strength, as such, it should be emphasized, nevertheless, that the factor of fiber length or staple length is important as a practical basis or "handle" for the selection of cottons which have other associated fiber properties in increasing desirability and which can give tire cords of higher tensile strength. It should be emphasized moreover, that as a practical matter, fiber length as determined by laboratory methods and, more particularly, staple length as designated by the classer provide an essential basis for the selection of cottons to meet the requirements of specific roll settings and drafts in manufacturing organizations.

At first glance, perhaps, the disclosure that the length of cotton fibers as such is of little importance to the strength of tire cord may be somewhat startling, and more particularly so, since the length of staple contributes appreciably to the strength of single yarns and woven fabrics and since it is a factor of such importance in determining the fineness of count to which a cotton can be spun. On further reflection, however, the negligible effect found for fiber length on tire-cord strength is entirely logical and in general agreement with that which properly should be expected.

By way of explanation, it would seem that the "ply-and cabled" construction of tire cord gives, in effect, greater continuity to the discontinuous cotton fibers composing it, and to what amounts to longer "effective" fiber lengths than occur in the case of single cotton yarns. The net benefit of these two "effects" on the strength of tire cord is comparatively large and relatively greater, the shorter the upper quartile length or staple of the cotton. Although strictly comparative data are not available, those at hand are of interest as follows: The 377 lots of tire cord composing this series ranged in strength from 10.8 to 21.4 pounds and averaged 17.9 pounds. The 384 lots of 22s single yarn, spun with respective optimum twists in relation to staple length and corresponding approximately to the 23s yarn spun with a constant twist for the tire cord series, ranged in skein strength from 49 to 142 pounds and averaged 95.8 pounds. Thus, on a basis of these figures, the range of strength for the tire cord is 59 percent of its mean, whereas the range of strength for the yarns is 97 percent of its mean. This difference of 38 percent is a relatively large one, and apparently is due to the relations and effects mentioned.

Moreover, the concepts expressed above and the facts borne out by the statistical data here presented as to the lack of any appreciable importance of fiber length, per se, to the strength of tire cord have been repeatedly confirmed in commercial practice over a period of many years, though perhaps not generally realized specifically as such. For example, it need only be recalled that, in the early days of the automobile industry, long staple American-Egyptian and sea island cottons were used in the manufacture of tire cords and that American-Egyptian cotton was, in fact, developed primarily for this purpose. With the passing of time, however, cottons of increasingly shorter lengths have been used successfully in the production of tire cord. Now, even appreciably stronger, better, and longer wearing tire cords are made from cottons with a staple length of 1-1/32 to 1-1/8 inches than formerly were made out of the extra long and specialty staples. It is appreciated, of course, that improvement in the quality and character of American upland cotton during the last 30 years, as well as substantial changes in design and construction of tire cords, of tires, of automobiles, of highways, and many other factors have contributed appreciably, in one way or another, to this end.

In view of the fact that all of the 23s single yarns used in the series of tire cord considered herein were spun with a twist multiplier of 4.00, according to the American Society for Testing Materials standard specification for 23/5/3 tire cord available at that time, the question arises as to what effect, if any, the constant factor of twist in the single yarns may have had on the observed lack of a relationship between upper quartile length and cord strength in this instance. Examining the staple lengths for the 377 duplicate lots of cottons, it is evident that a wide range in length was involved, insofar as American upland cotton is concerned, and that much shorter cottons were included than is the case in commercial practice.

More specifically, the cottons varied in staple length from 5/8 inch to 1-5/16 inches, covered a range of 11/16 inch, and averaged 31/32 inch. Grouped into class intervals of 1/16 of an inch, the cottons were distributed according to staple length as follows: 3/4 inch and shorter, 2 percent; 13/16 inch, 6 percent; 7/8 inch, 16 percent; 15/16 inch, 27 percent; 1 inch, 30 percent; 1-1/16 inches, 9 percent; 1-1/8 inches, 6 percent; and 1-3/16 inches and longer, 4 percent. The few cottons shorter than 3/4 inch and longer than 1-1/4 inches amounted to only several tenths of 1 percent.

According to the data obtained in the laboratories of the Cotton and Fiber Branch, Office of Marketing Services, from the spinning and testing of many hundreds of cottons over a wide range of staple lengths for a period of years, a twist multiplier of 4.0 is optimum for single yarns manufactured from cottons with a staple length of 1-1/16 inches or closely thereabout. Thus, almost half of the yarns used in these cords did, in fact, possess close to their optimum twist. The yarns made from the cottons longer than 1-1/16 inches, however, contained slightly more twist than their respective optimum; nevertheless, the excess twist was so relatively small and the cottons in this length category were so few in number that such could not have appreciably affected the results.

In the case of the yarns manufactured from cottons shorter than 1-1/16 inches, they possessed less twist than that representing their respective optimum and, obviously, the disparity increased as the staple length became shorter. For example, the optimum twist multiplier for yarns made from cottons of different staple lengths within this zone are as follows: 1 inch, 4.25; 15/16 inch, 4.45; 7/8 inch, 4.70; 13/16 inch, 5.0; 3/4 inch, 5.35; 5/8 inch, 5.35. Thus, on a basis of the known yarn-strength-twist relationships, the strength of the single yarns spun from such cottons undoubtedly was proportionally less with decrease in staple length, as compared with what it would have been, if the yarns had possessed their respective optimum twist. However, to what extent the constant twist of the single yarns did affect the cord strengths, if any, cannot be told from the data available from this series, since no tests were made bearing on this particular factor.

During the 10-year period intervening since the growth of the cottons used in this study, considerable improvement has been made in fiber and spinning quality, through the processes of plant breeding and selection. A number of new or improved varieties are in commercial production today. Substantial improvements also have been made, during the same period, in tire-cord and tire construction which, together with improved fiber quality and more effective utilization of the fiber properties, are giving tire cords which render appreciably better service performance than did those of former years. In the light of the foregoing considerations, therefore, it would seem reasonable to expect that, if the analyses reported herein were conducted with selected cottons out of current production and with tire cords of modern construction, the results obtained perhaps would be better, in a number of particulars, than those found in this study.

Opportunities exist for still further improvement in cotton-fiber quality, in tire-cord construction, and in tire construction. However, if the meaning of laboratory measurements of tire-cord properties in terms of their relation to the practical service performance and life wear of tires were better known than they now are, and if the needs of manufacturers with respect to cotton fiber properties of tires were more precisely known than at present, cotton breeders and southern agriculture would be in a much stronger position for working towards such goals and for meeting those cotton-quality requirements. Today, as in the past, there seem to exist a number of conflicting views and no little confusion about a number of important points and practical problems with respect to tire cord. To illustrate: A few years ago, tire cords of high stretch and super twist were in greatest favor with the industry; now, tire cords with low stretch and minimum twist appear to be desired by the industry. Which type of tire cord is better and why? And how much of this and that of other properties do tire cords really need for the best service performance and life wear? The answers, of course, are not simple and easy to determine. On the contrary, obtaining adequate proof for the correct answers is a highly complex and difficult matter. This status suggests that the most rapid and effective progress will and can be made along these lines in the future, only by the closest possible "two-way" cooperation between key workers in industry and agriculture. In brief, this means a free and frank exchange of viewpoints, data, and criticism, at all times, on problems of mutual interest.

GRAPHIC CHARTS

Scatter diagrams have been used extensively in the making of interpretations in connection with this study, but only a limited number are included in this report. By using the equations developed for one or more of the fiber properties under consideration, an estimated value of tire-cord strength or tire-cord elongation can be obtained for each cotton, which reflects the effect of the separate and variously combined fiber properties. The estimated value, when plotted against its corresponding actual value, furnishes a picture of the status of each cotton, and a series of such plotted dots graphically reveals what is associated with a group of cottons. The vertical and horizontal scales, being identical in all charts of a corresponding type, make possible direct and easy graphic comparison of the precision of the relationships expressed by the different equations. Thus, pictorial comparisons may be made of each segment of results obtained throughout an entire series, even though varying numbers of fiber properties are included and in spite of the fact that various units of measure are necessitated by the different tests.

For assistance in visualizing the principal findings obtained in this study, graphic charts are presented in figures 1 to 26 as follows:

Figures 1 to 12 show the relationships between fiber properties and tire-cord strength. If all the dots plotted on such charts should fall on the 45° line drawn in any of the graphs, this would indicate perfect

agreement between the estimated and actual values for tire-cord strength. As plotted, therefore, a dot below the line indicates that the strength of the cord has been overestimated and a dot above the line, underestimated.

Figures 13 to 20 illustrate the relationships between fiber properties and tire-cord elongation at the 10-pound load.

Figures 21 to 23 reveal the relationships between the three pairs of tire-cord properties considered.

Figures 24 to 26 show the relationship between each of the three tire-cord properties and skein strength of 23s singles yarn.

No graphic charts are presented for the relationships that exist between fiber properties and tire-cord elongation at the point of rupture, as the correlation results obtained with both elongation measures are similar in a number of particulars.

* * * * * * * * * * *

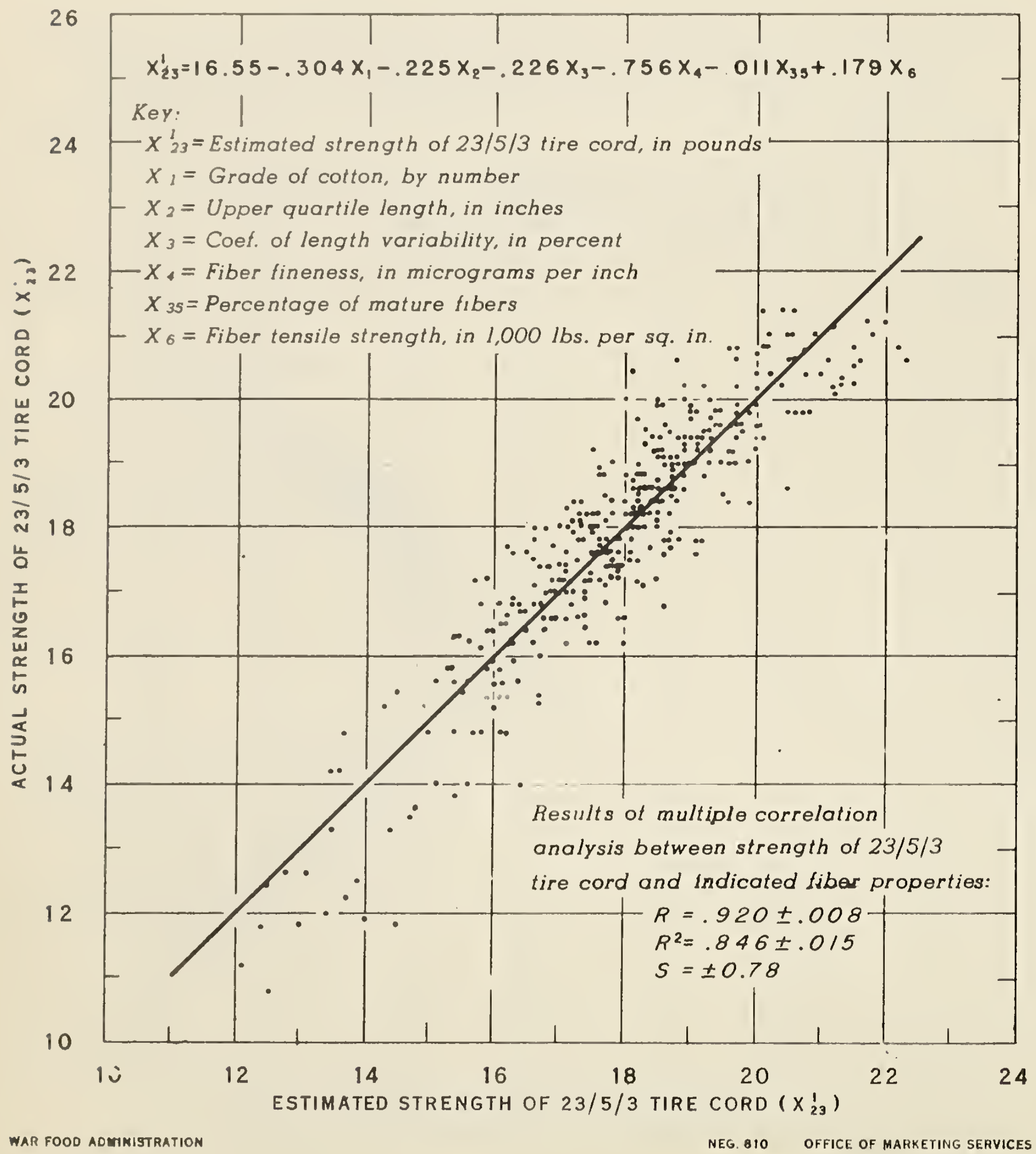


FIGURE 1—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on the Multiple Regression Equation (1)

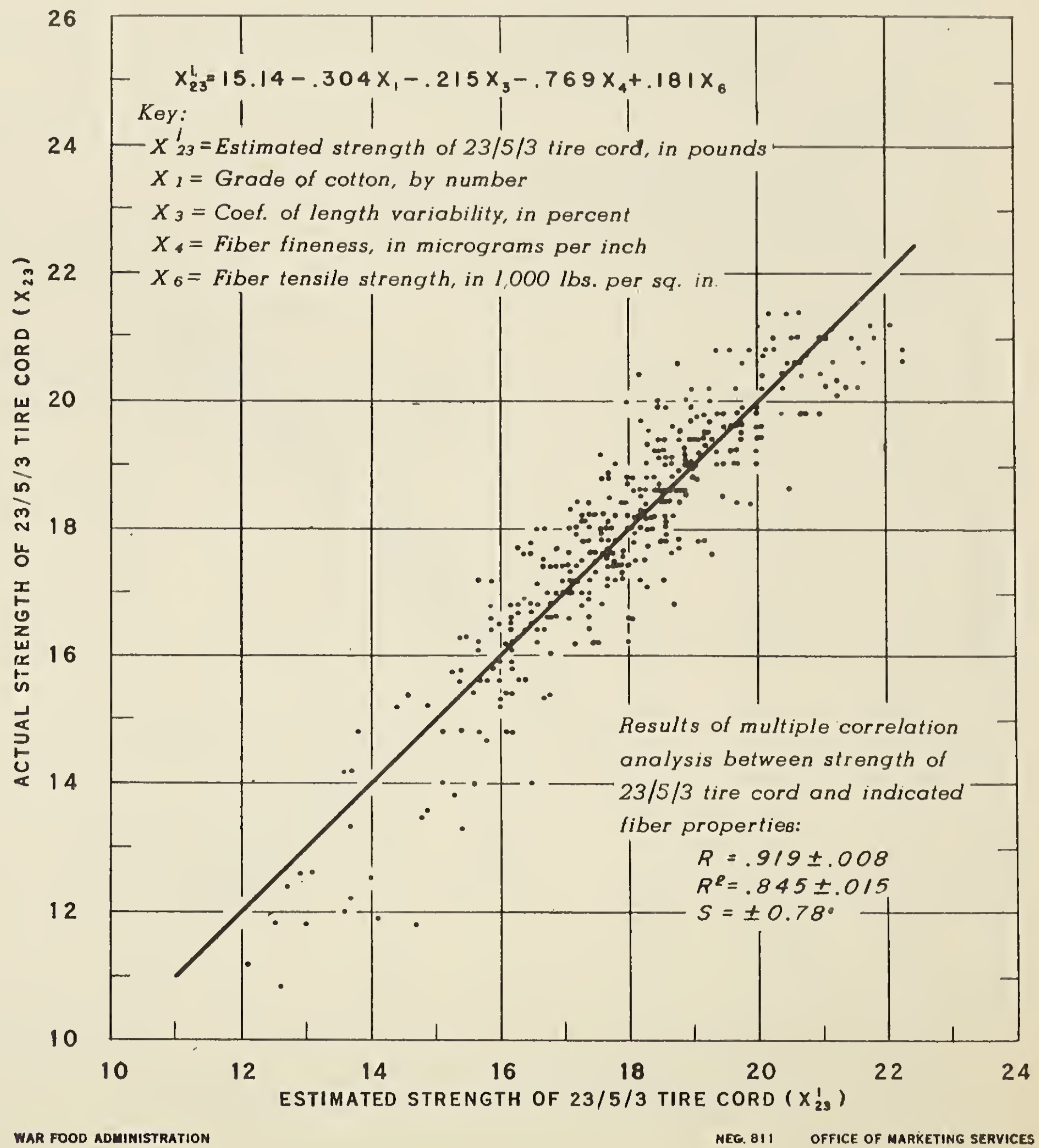
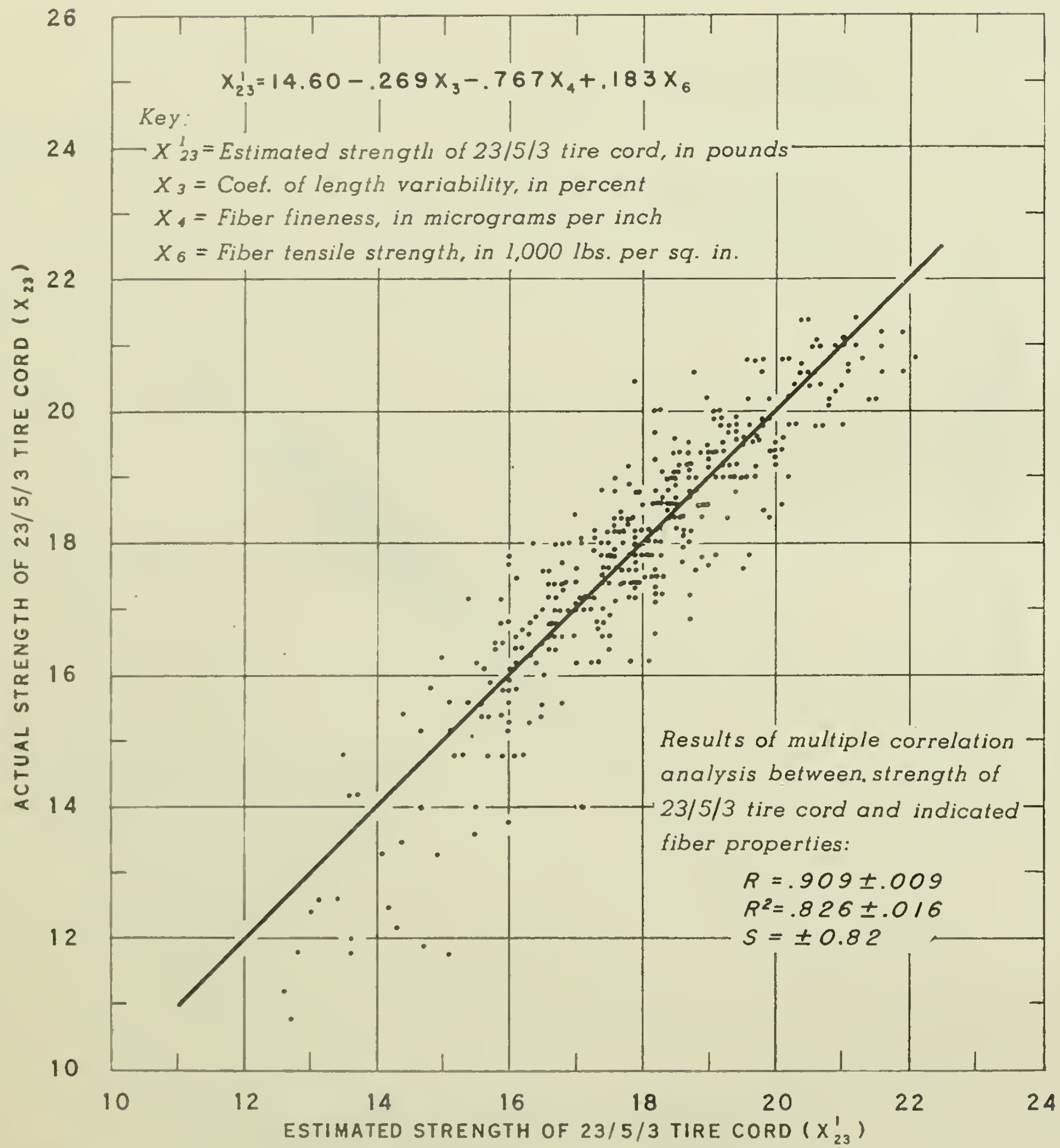
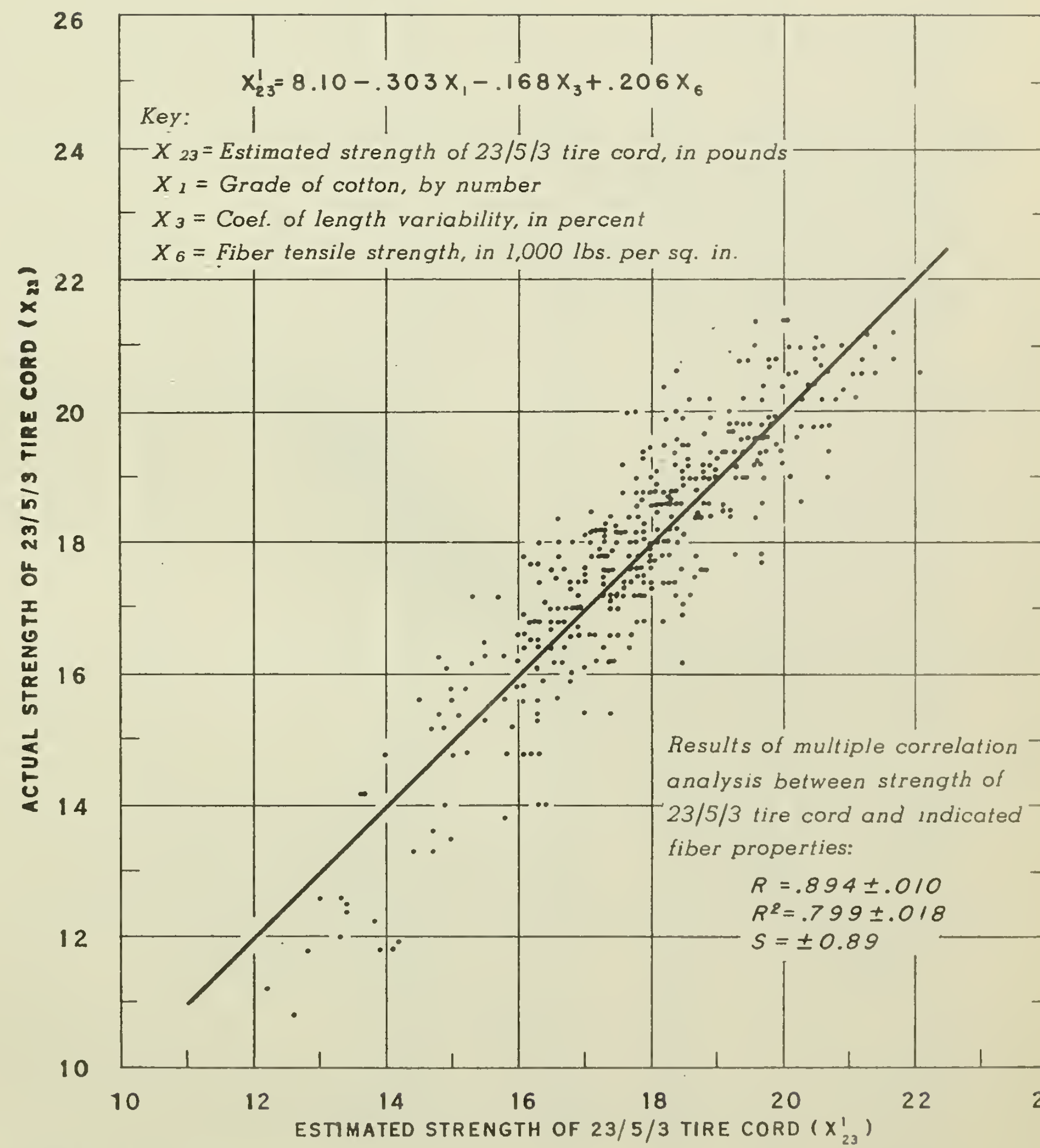


FIGURE 2 - Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on the Multiple Regression Equation (8)



WAR FOOD ADMINISTRATION NEG 812 OFFICE OF MARKETING SERVICES

FIGURE 3—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on the Multiple Regression Equation (9)



WAR FOOD ADMINISTRATION NEG. 813 OFFICE OF MARKETING SERVICES

FIGURE 4—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on the Multiple Regression Equation (11)

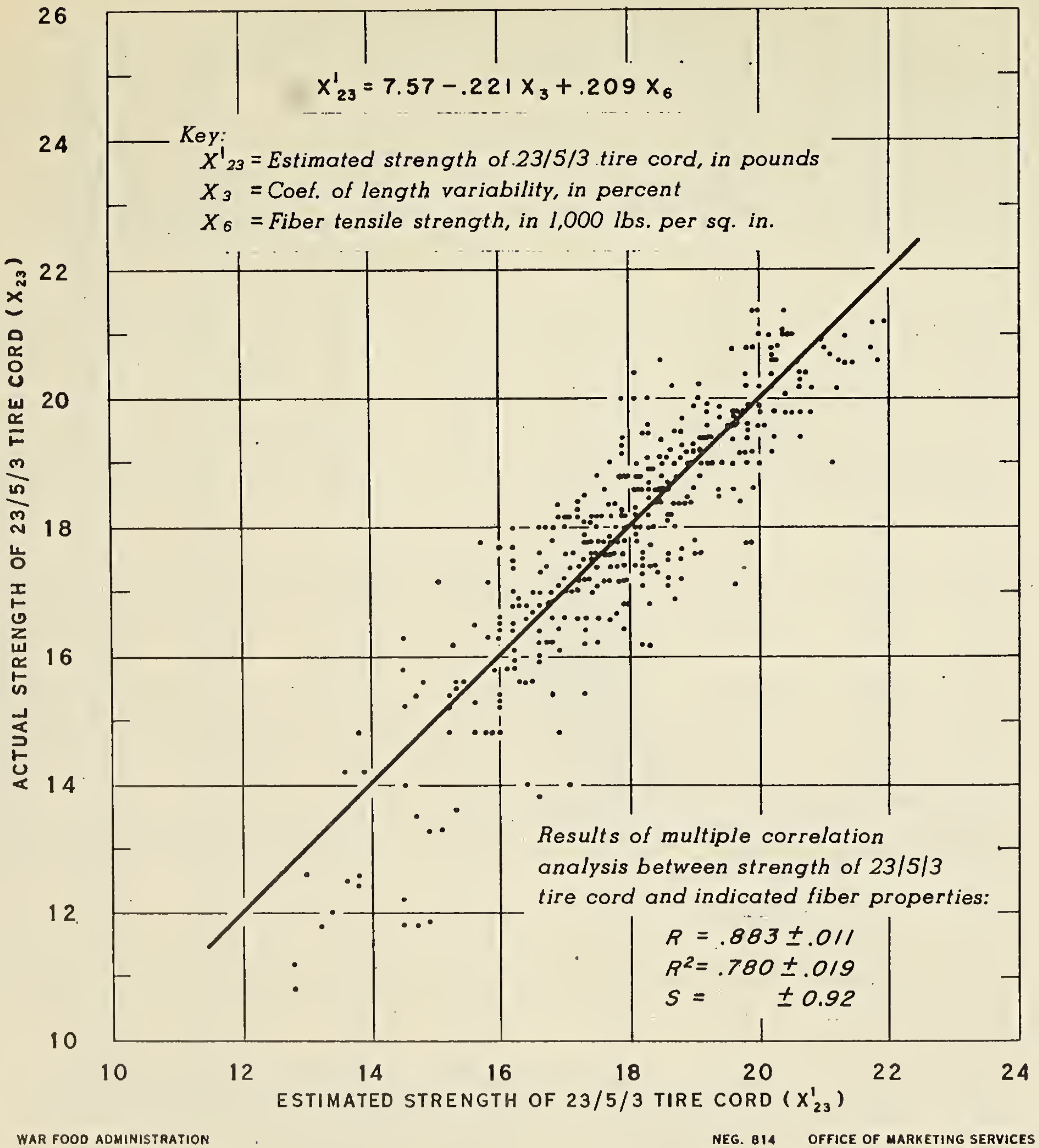


FIGURE 5—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on the Multiple Regression Equation (12)

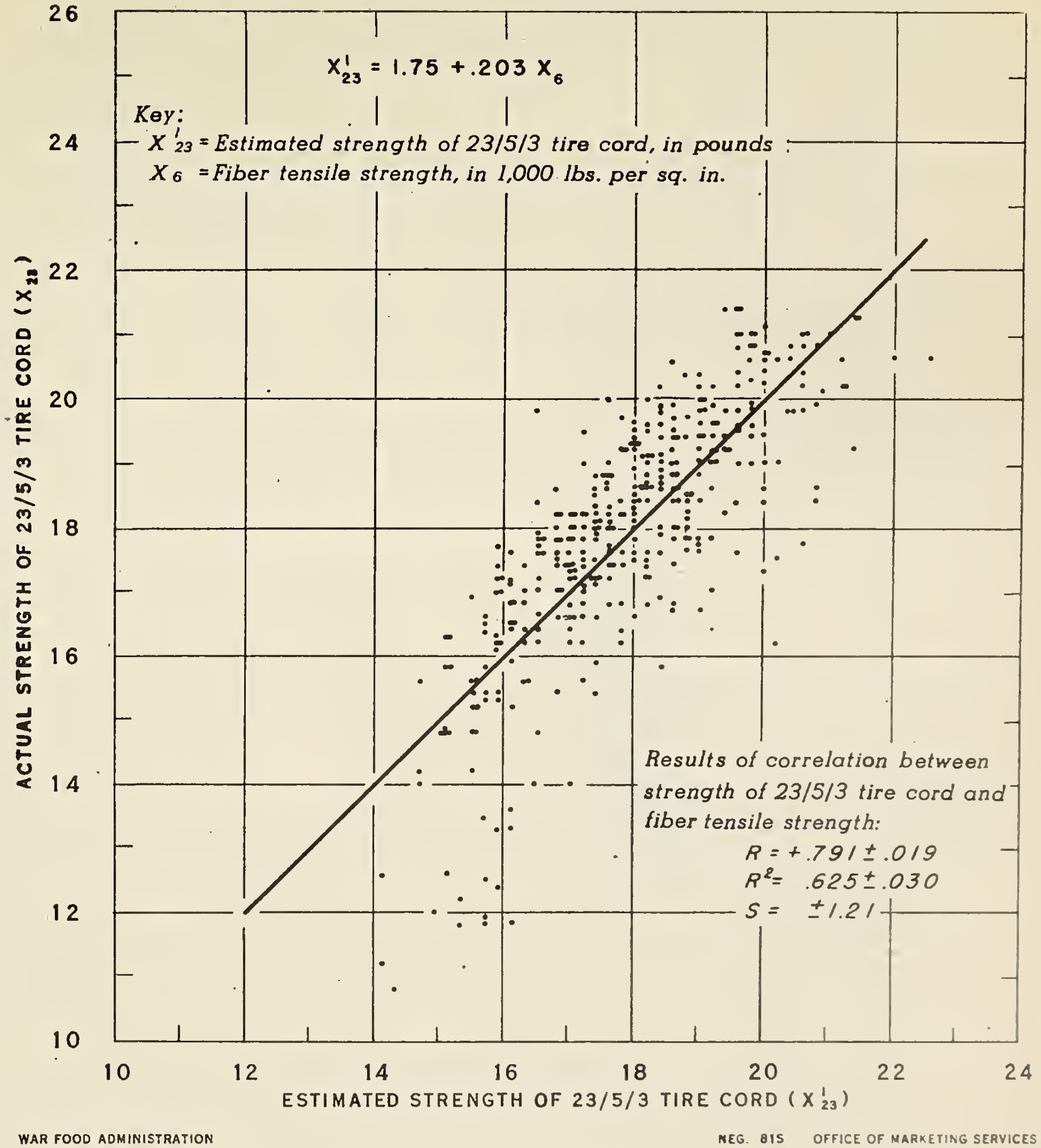


FIGURE 6—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on Equation (16) Derived from Simple Correlation

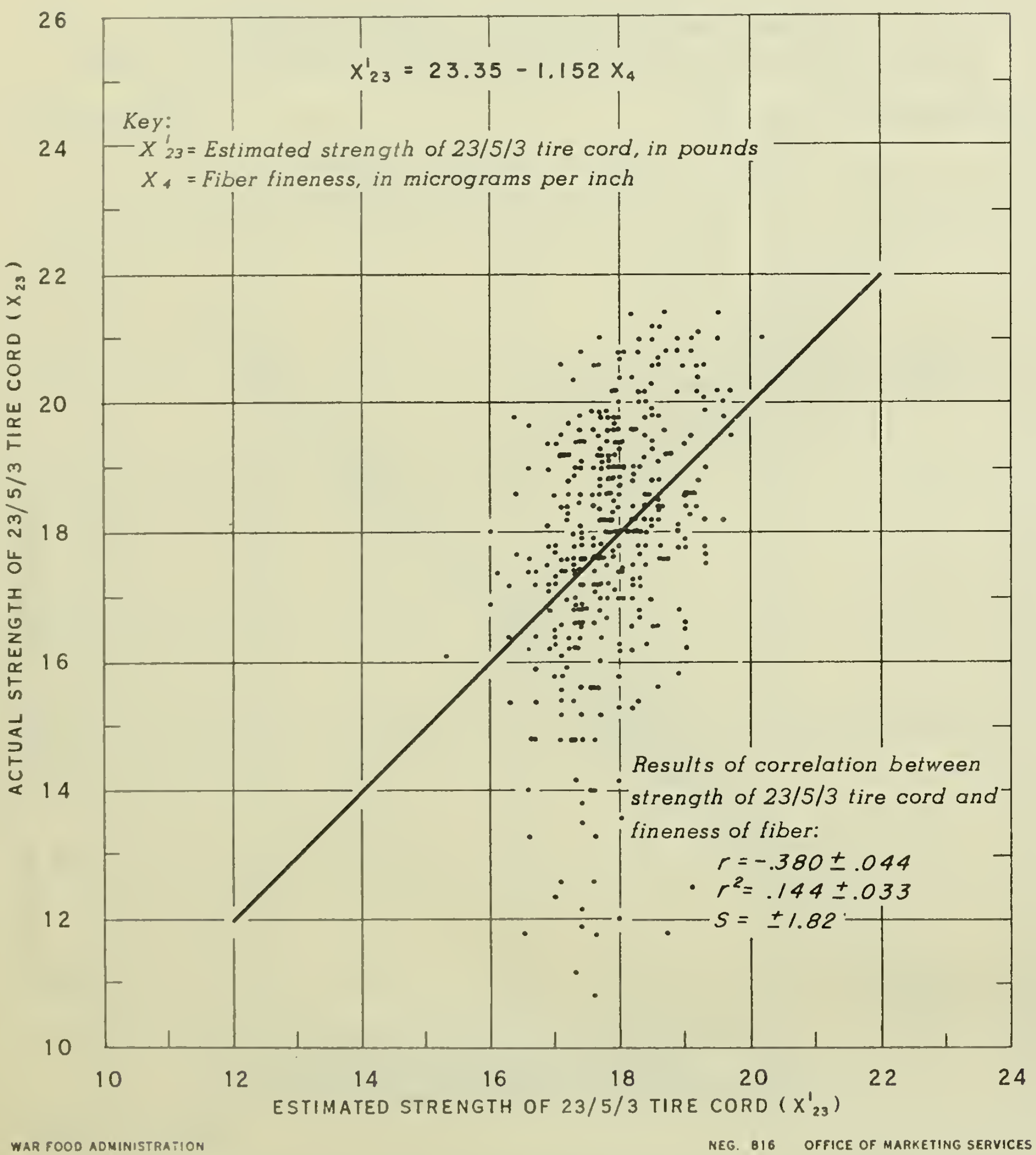


FIGURE 7—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on Equation (17) Derived from Simple Correlation

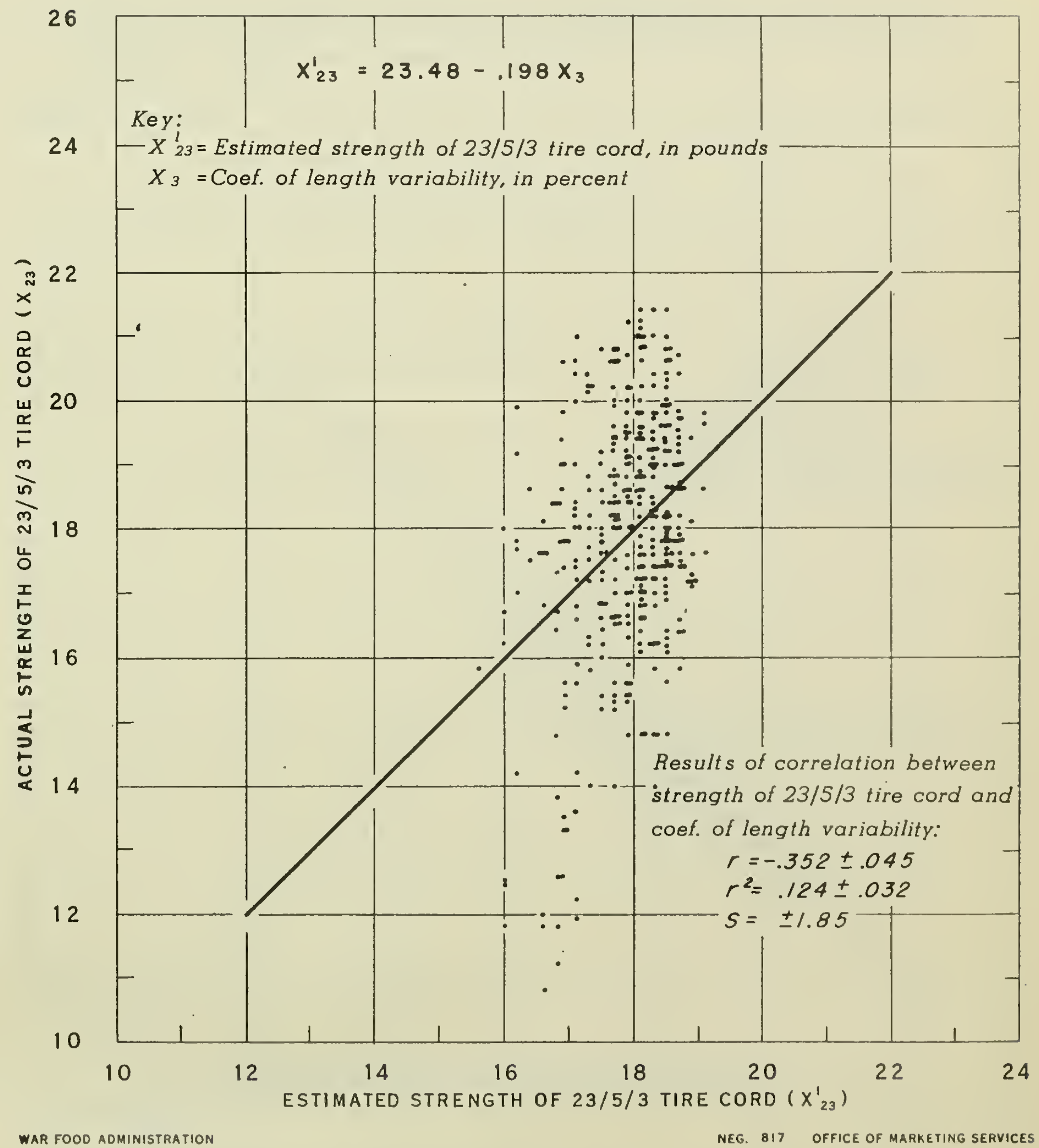


FIGURE 8—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on Equation (18) Derived from Simple Correlation

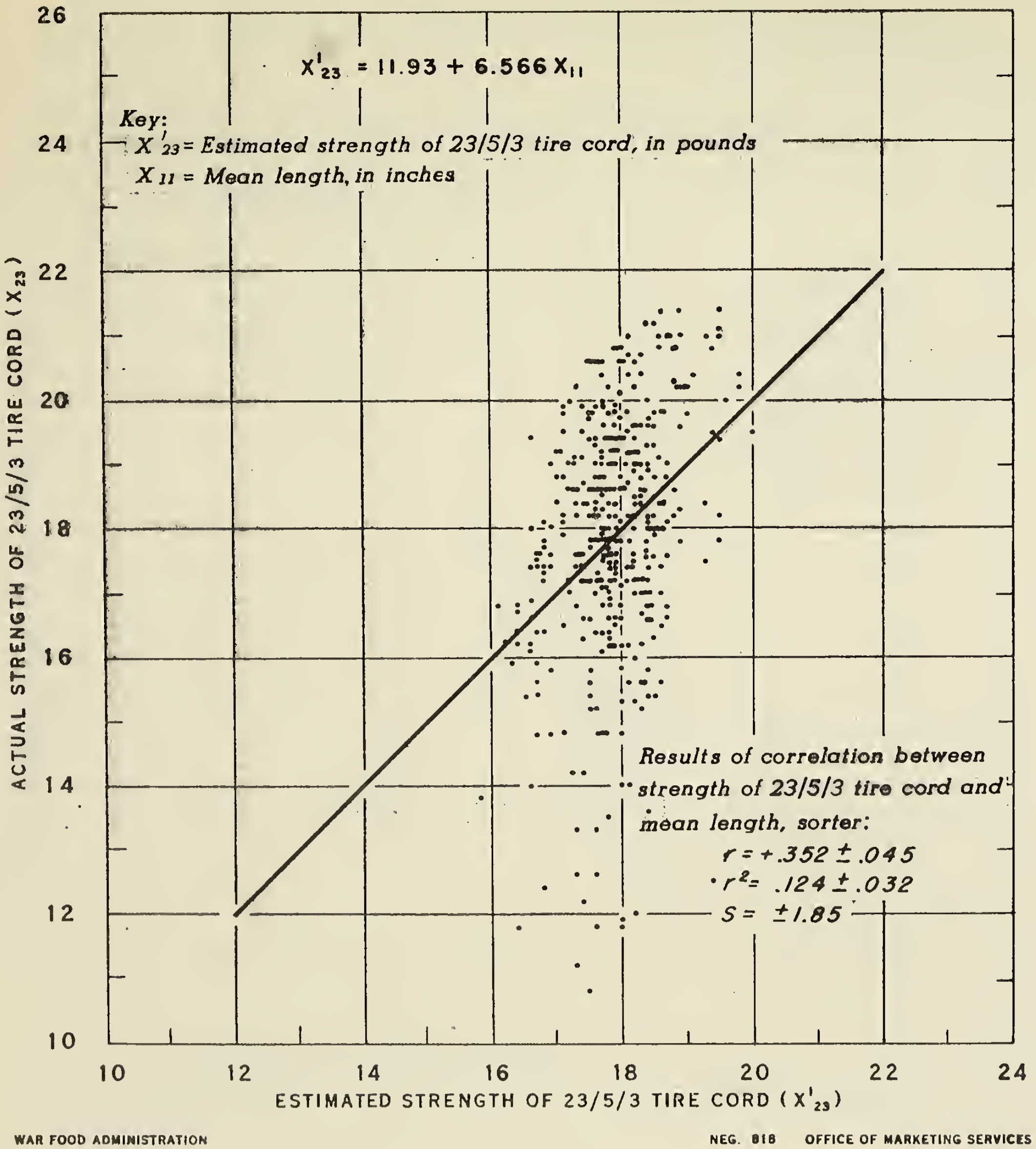


FIGURE 9—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on Equation (19) Derived from Simple Correlation

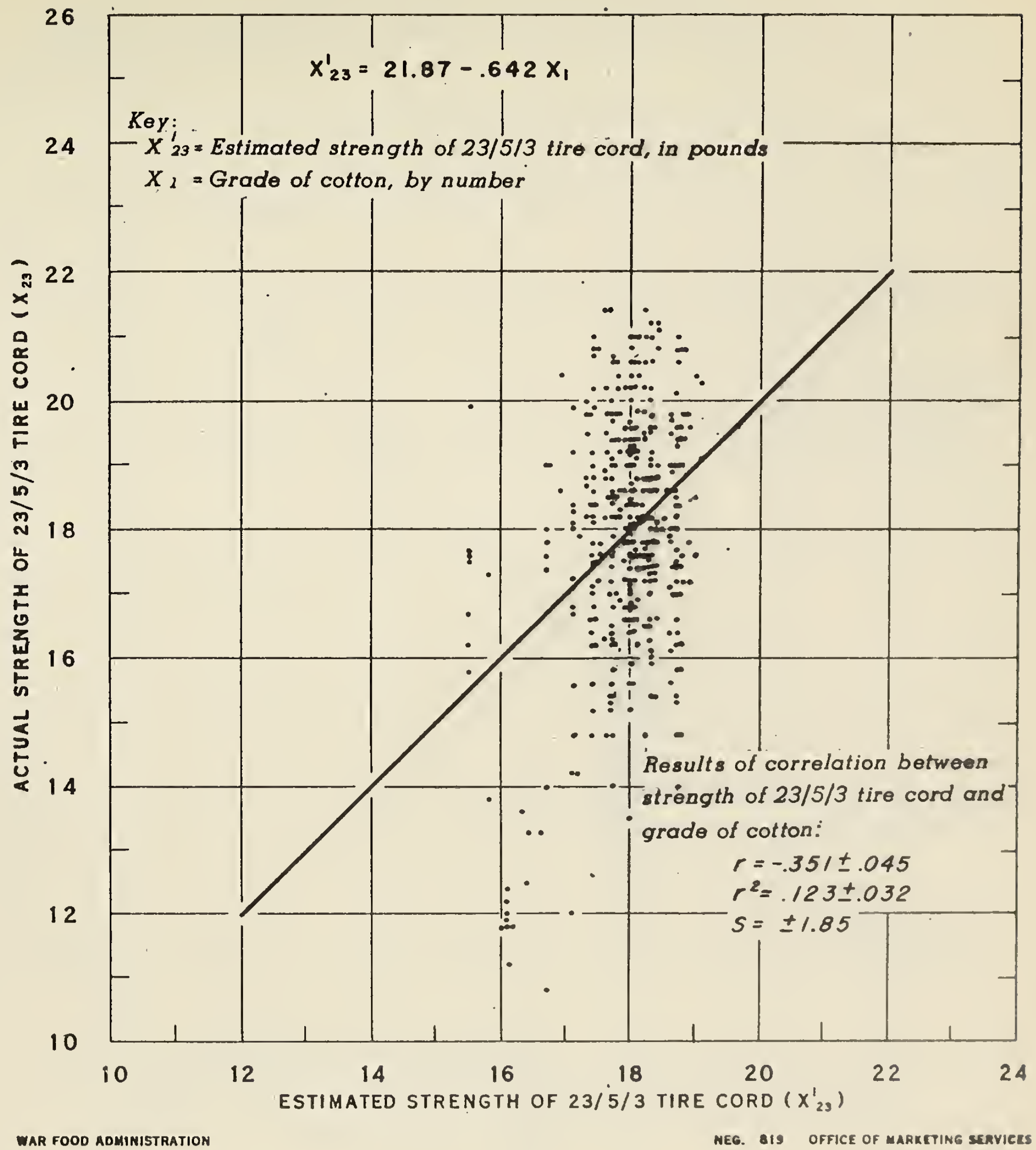


FIGURE 10—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on Equation (20) Derived from Simple Correlation

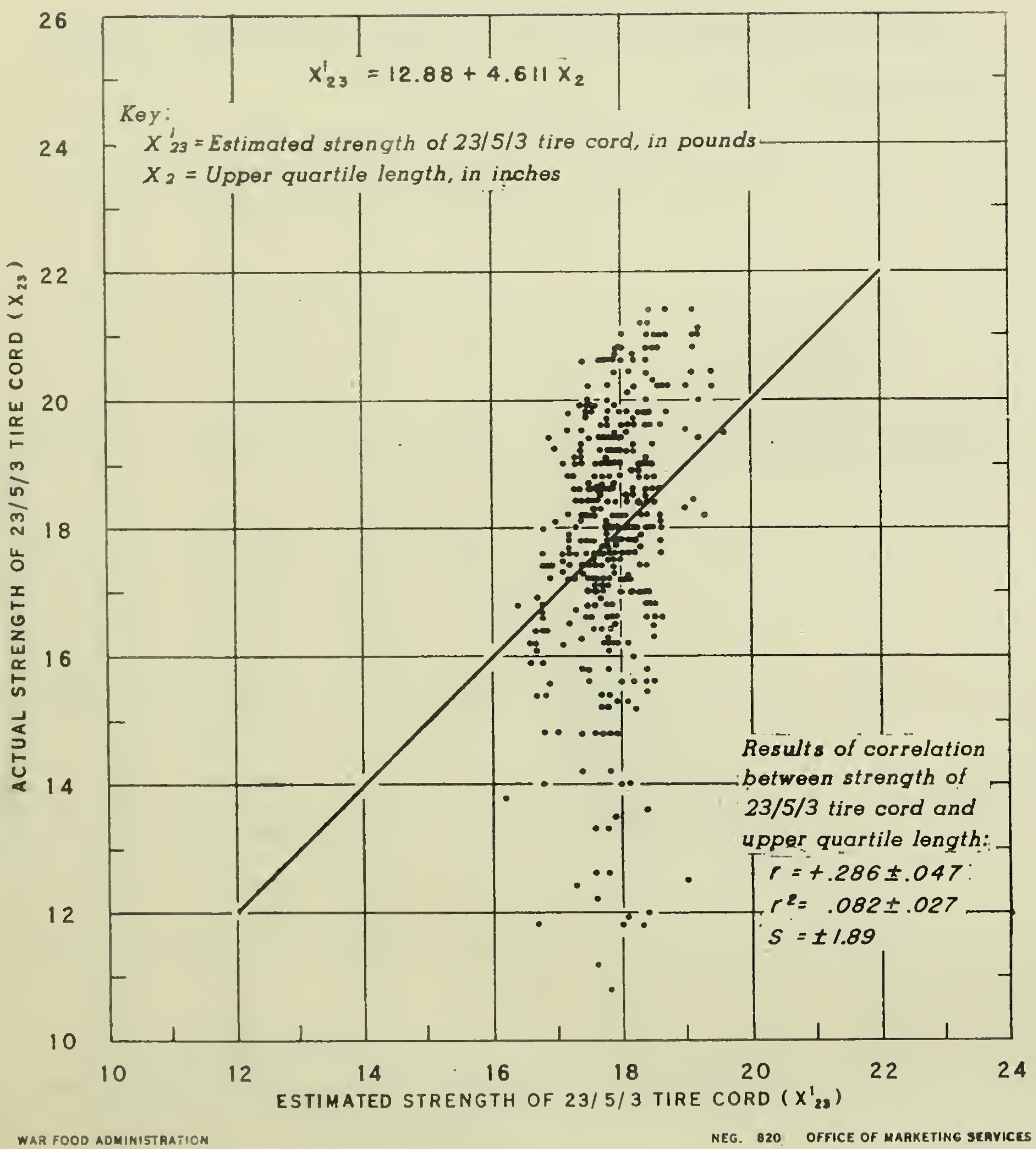


FIGURE 11—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on Equation (21) Derived from Simple Correlation

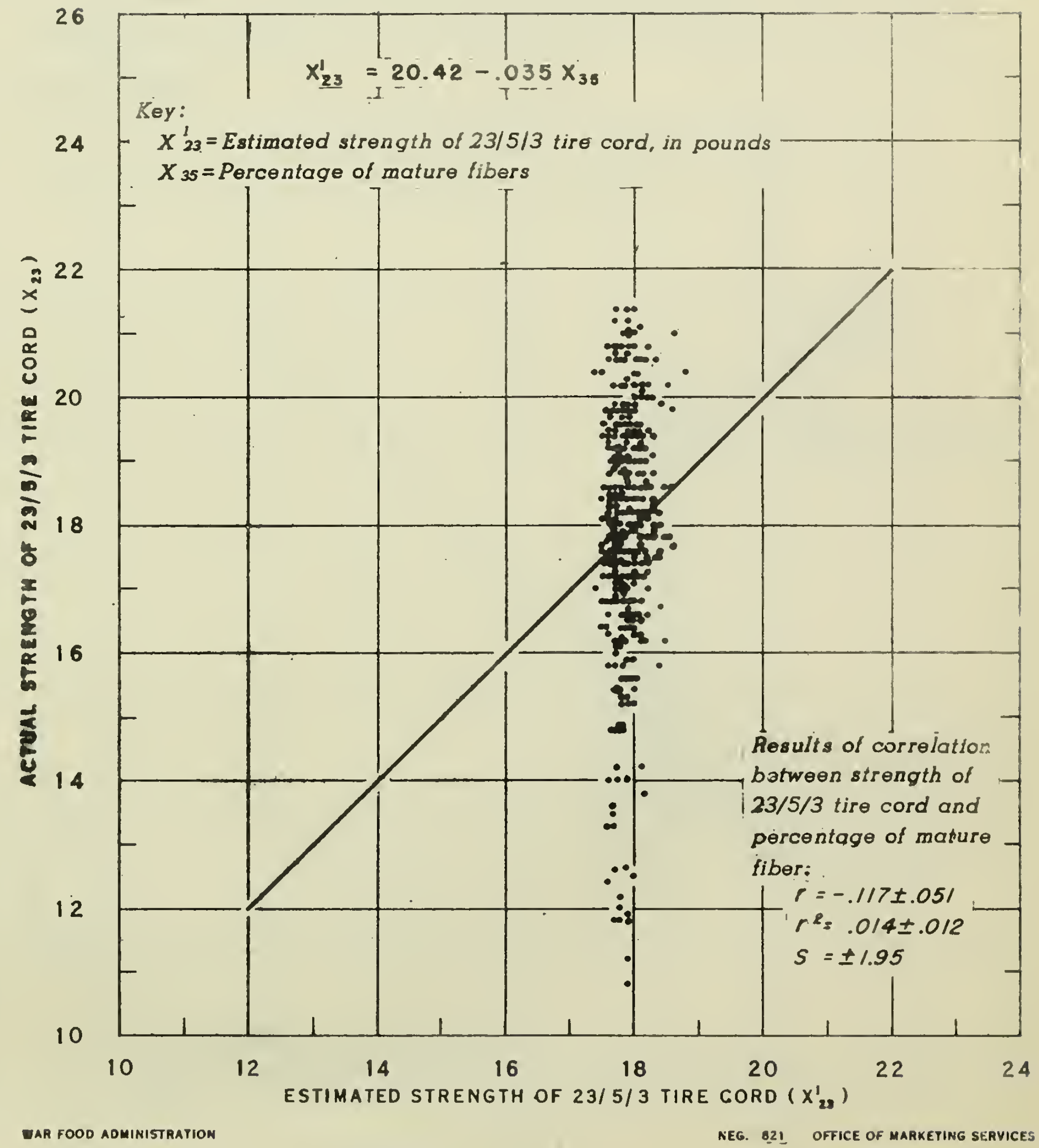
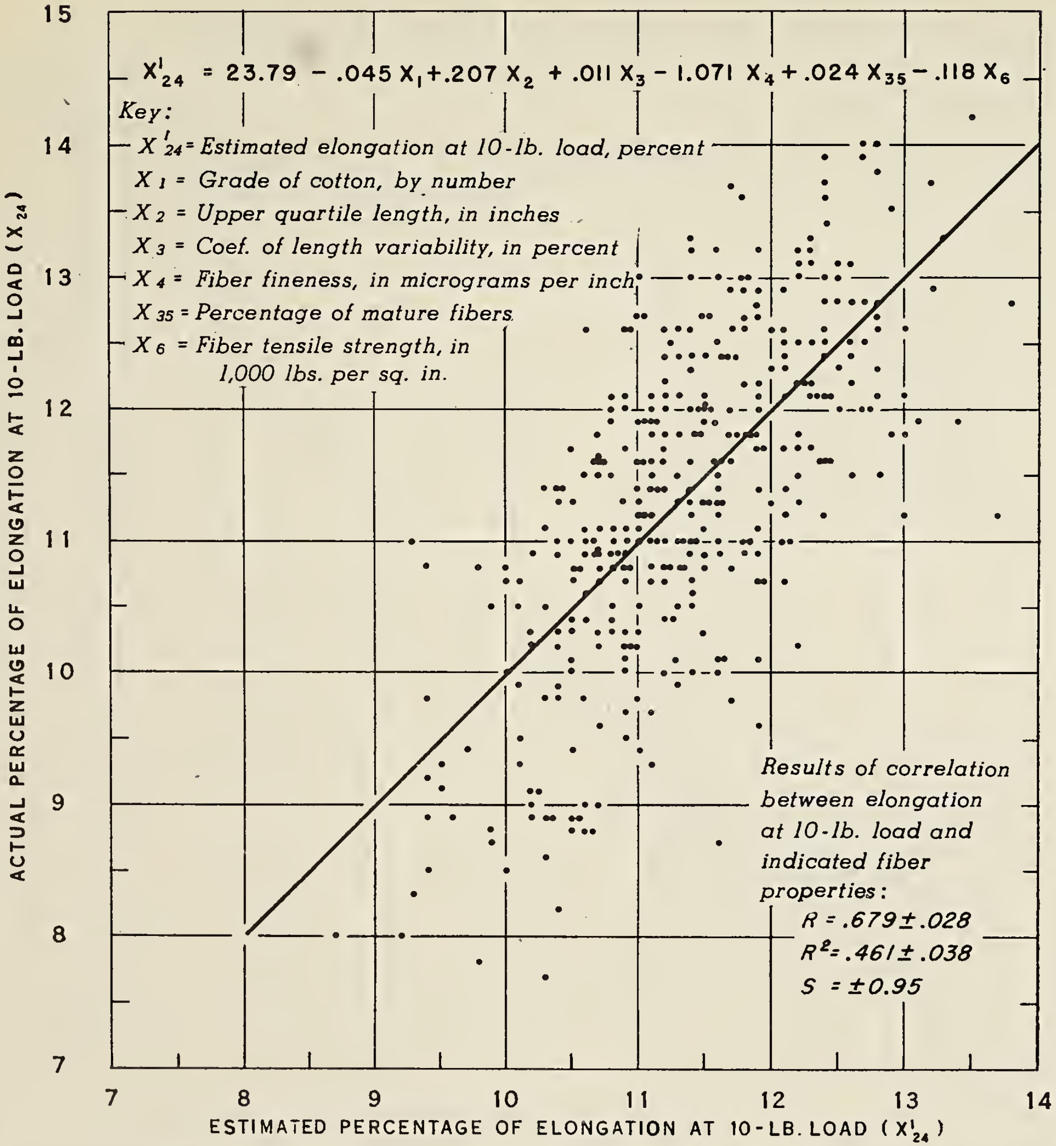
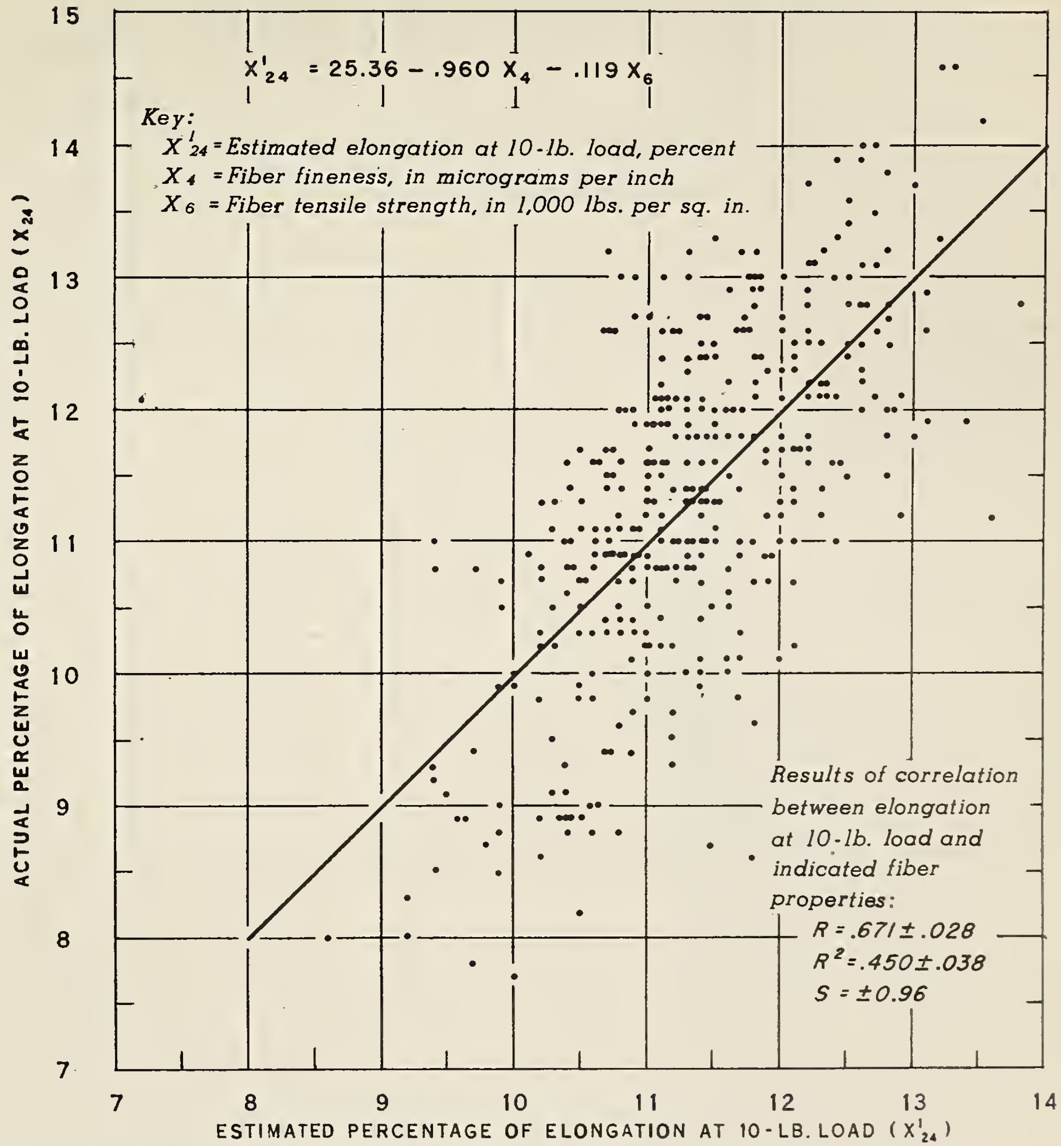


FIGURE 12—Comparison of Actual Strength of 23/5/3 Tire Cord with Estimated Strength of 23/5/3 Tire Cord Based on Equation (23) Derived from Simple Correlation



WAR FOOD ADMINISTRATION NEG. 822 OFFICE OF MARKETING SERVICES

FIGURE 13—Comparison of Actual Elongation of 23/5/3 Tire Cord at 10-lb. Load with Estimated Elongation of 23/5/3 Tire Cord Based on the Multiple Regression Equation (28)



WAR FOOD ADMINISTRATION NEG. 823 OFFICE OF MARKETING SERVICES

FIGURE 14—Comparison of Actual Elongation of 23/5/3 Tire Cord at 10-lb. Load with Estimated Elongation of 23/5/3 Tire Cord Based on the Multiple Regression Equation (36)

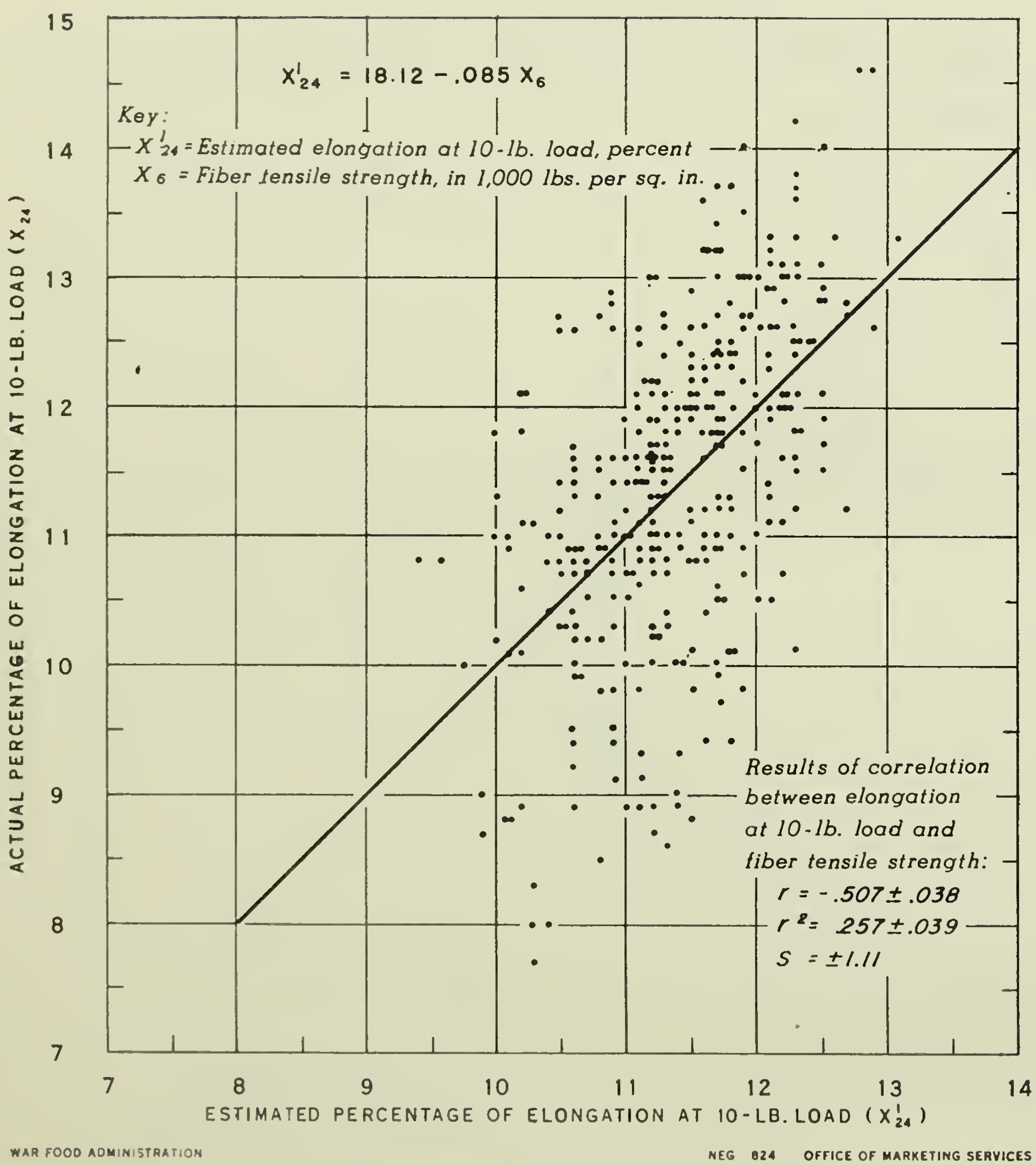


FIGURE 15—Comparison of Actual Elongation of 23/5/3 Tire Cord at 10-lb. Load with Estimated Elongation of 23/5/3 Tire Cord Based on Equation (39) Derived from Simple Correlation

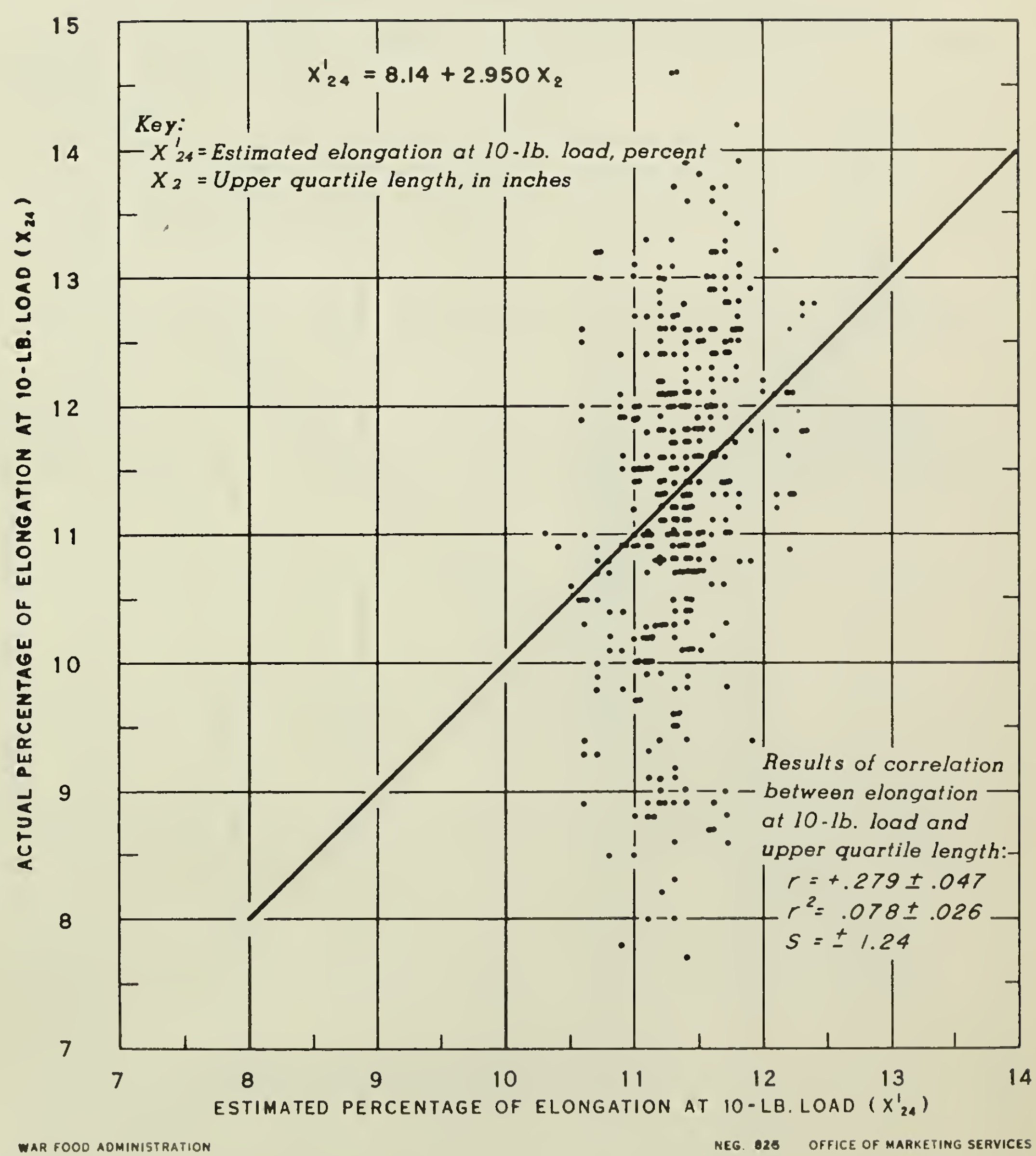


FIGURE 16—Comparison of Actual Elongation of 23/5/3 Tire Cord at 10-lb. Load with Estimated Elongation of 23/5/3 Tire Cord Based on Equation (40) Derived from Simple Correlation

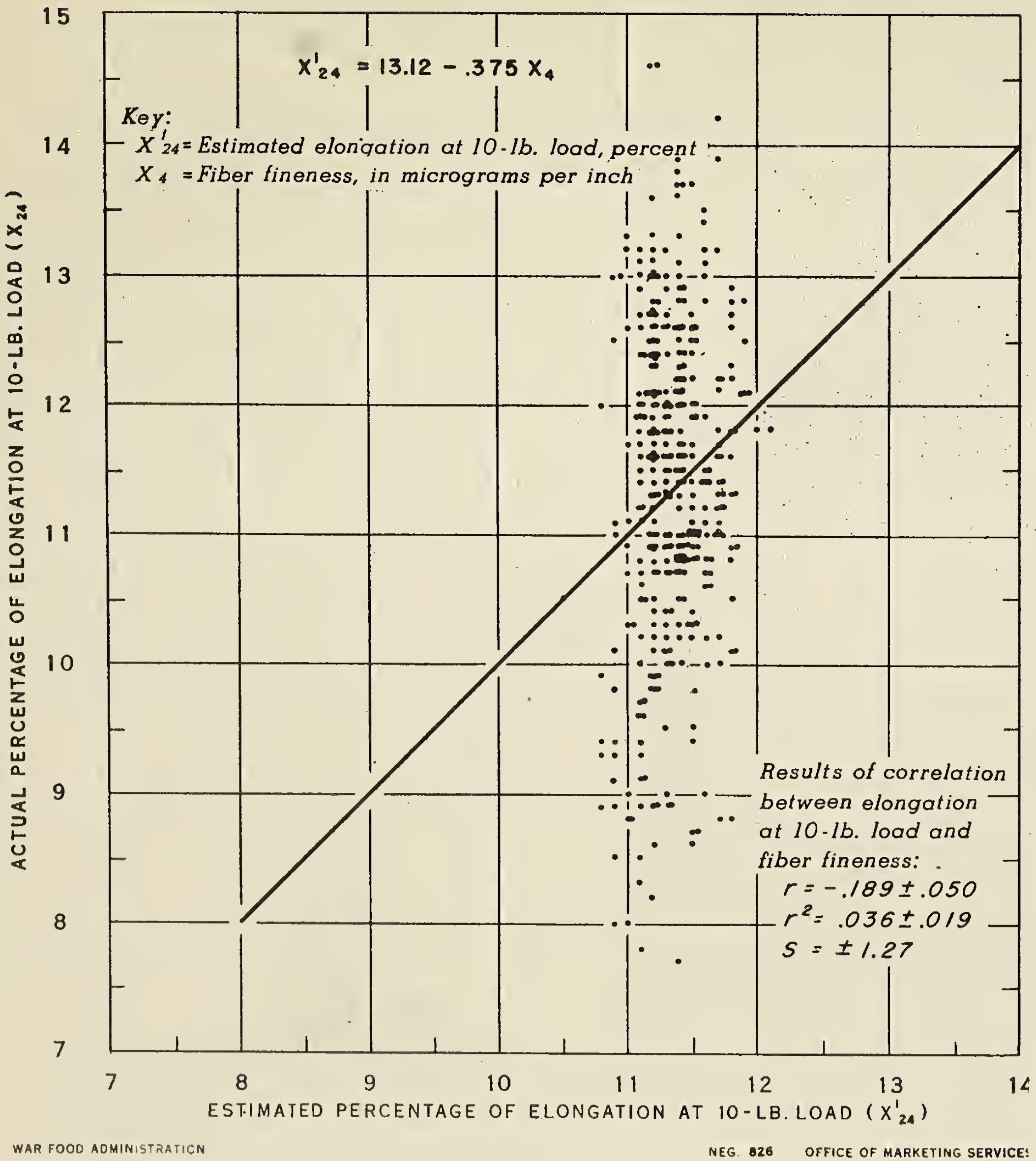


FIGURE 17—Comparison of Actual Elongation of 23/5/3 Tire Cord at 10-lb Load with Estimated Elongation of 23/5/3 Tire Cord Based on Equation (41) Derived from Simple Correlation

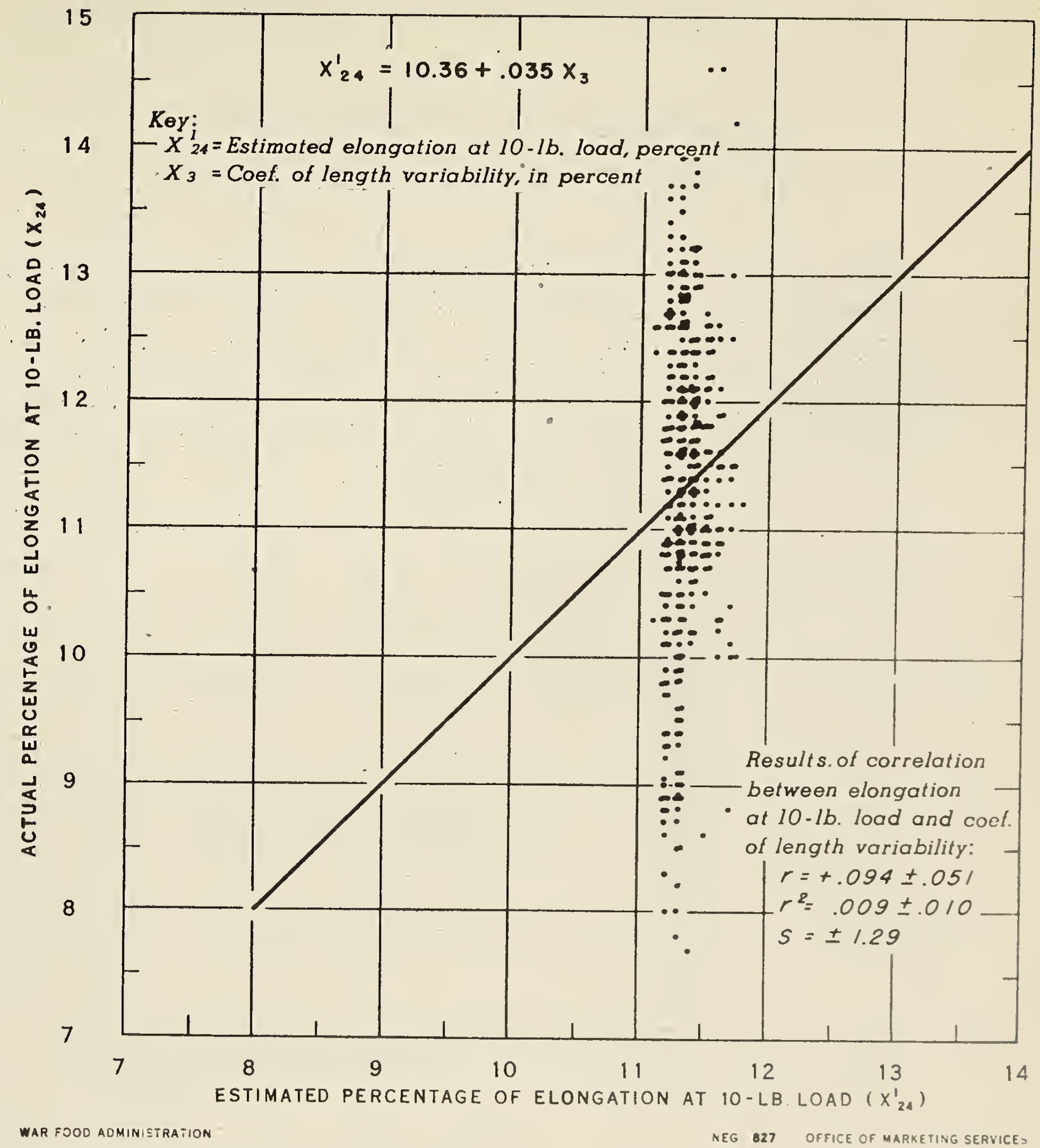


FIGURE 18—Comparison of Actual Elongation of 23/5/3 Tire Cord at 10-lb Load with Estimated Elongation of 23/5/3 Tire Cord Based on Equation (42) Derived from Simple Correlation

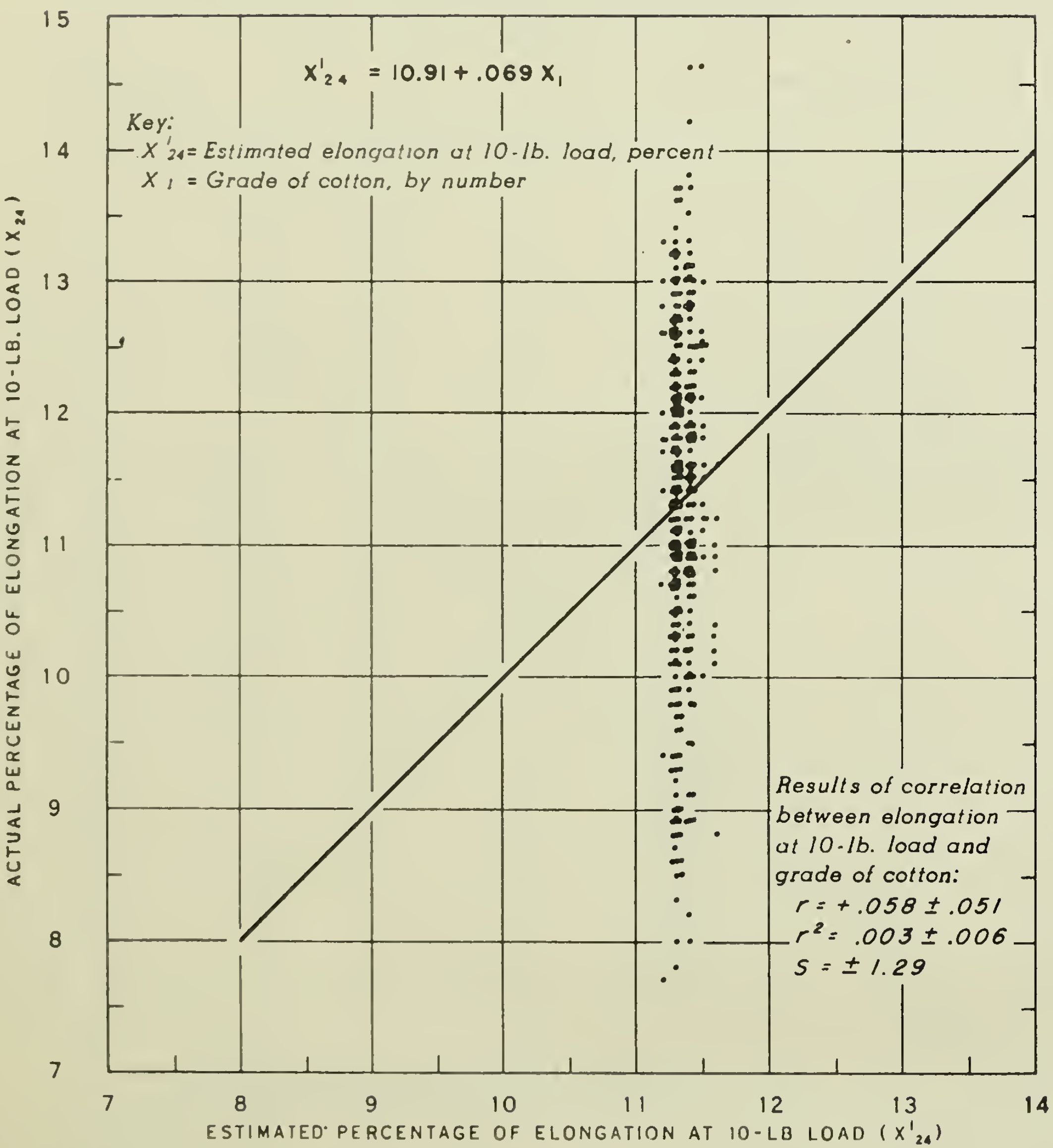


FIGURE 19—Comparison of Actual Elongation of 23/5/3 Tire Cord at 10-lb. Load with Estimated Elongation of 23/5/3 Tire Cord Based on Equation (43) Derived from Simple Correlation

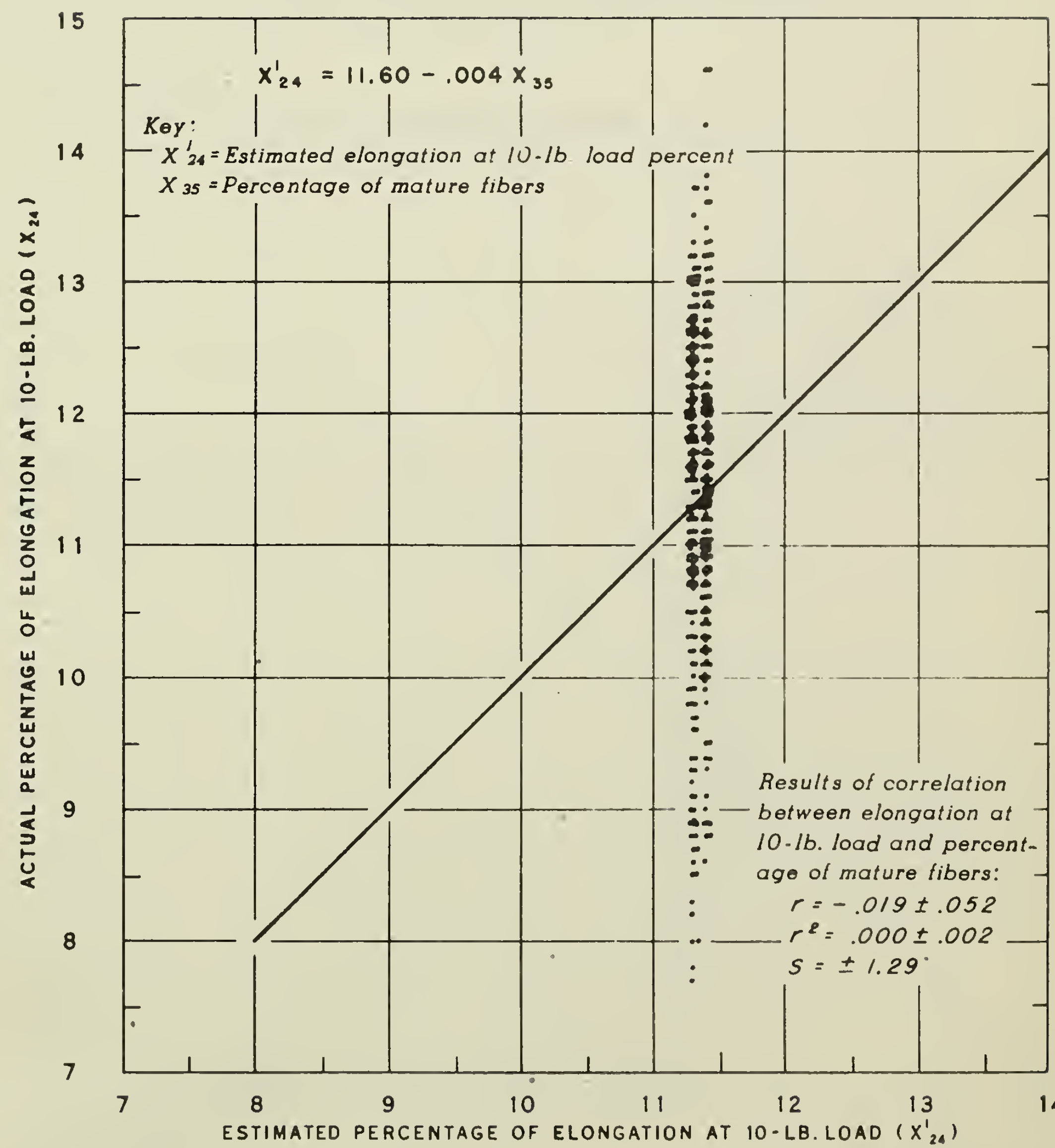
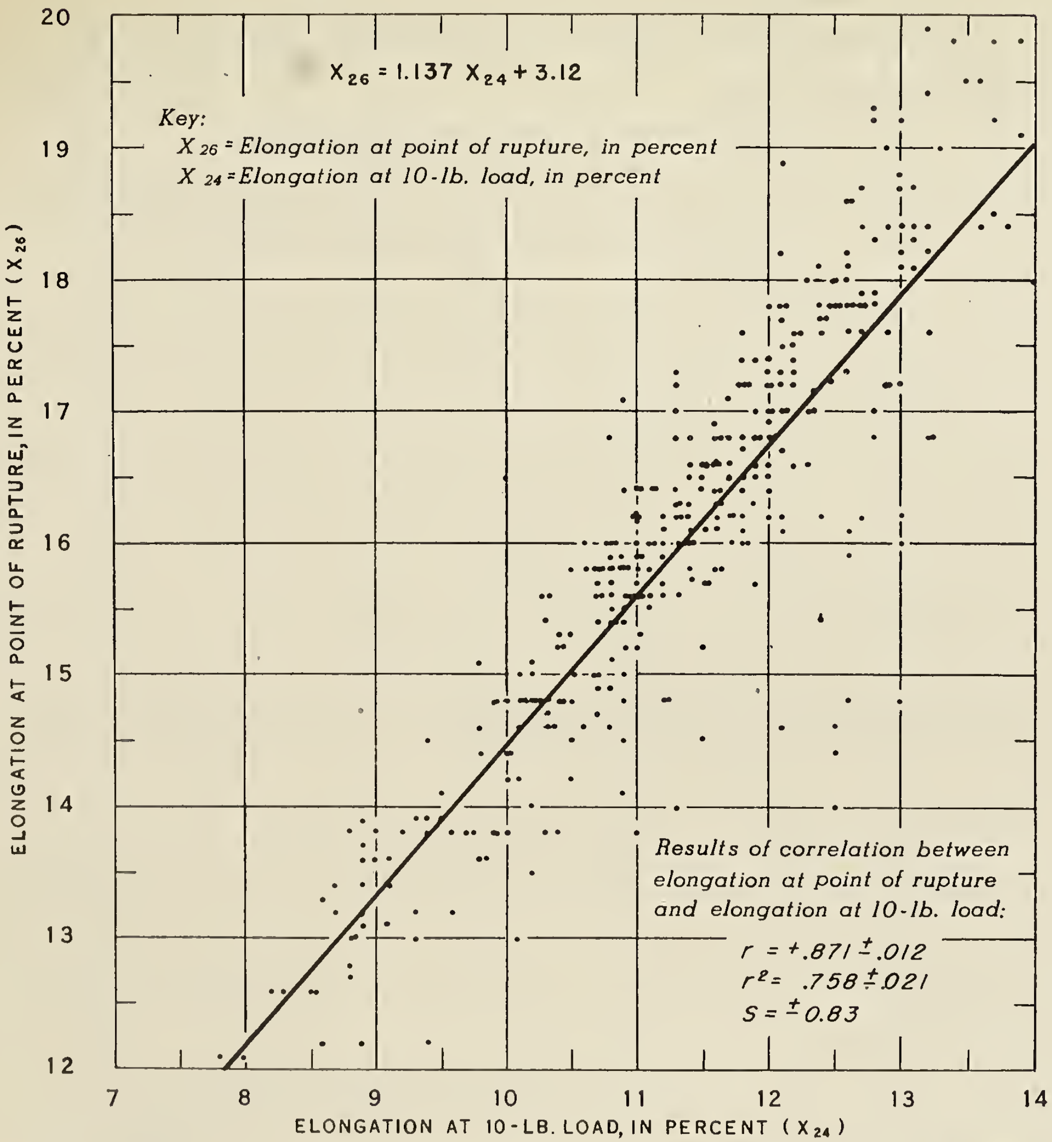
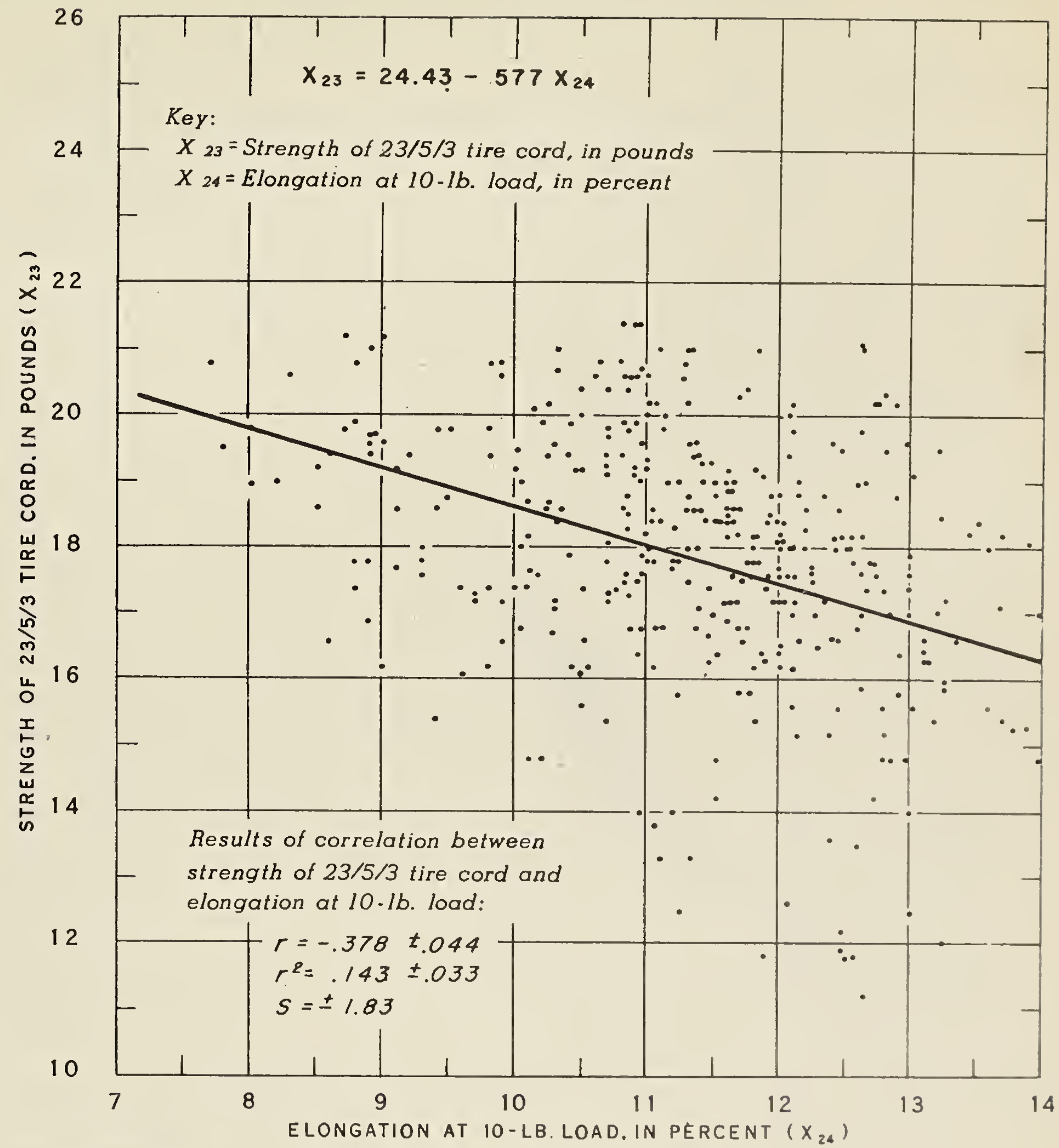


FIGURE 20—Comparison of Actual Elongation of 23/5/3 Tire Cord at 10-lb. Load with Estimated Elongation of 23/5/3 Tire Cord Based on Equation (44) Derived from Simple Correlation



WAR FOOD ADMINISTRATION NEG. 830 OFFICE OF MARKETING SERVICES

FIGURE 21 – Relationship between Elongation of 23/5/3 Tire Cord at Point of Rupture and Elongation at 10-lb. Load



WAR FOOD ADMINISTRATION NEG 831 OFFICE OF MARKETING SERVICES

FIGURE 22 – Relationship between Strength of 23/5/3 Tire Cord and Percentage of Elongation at 10-lb. Load

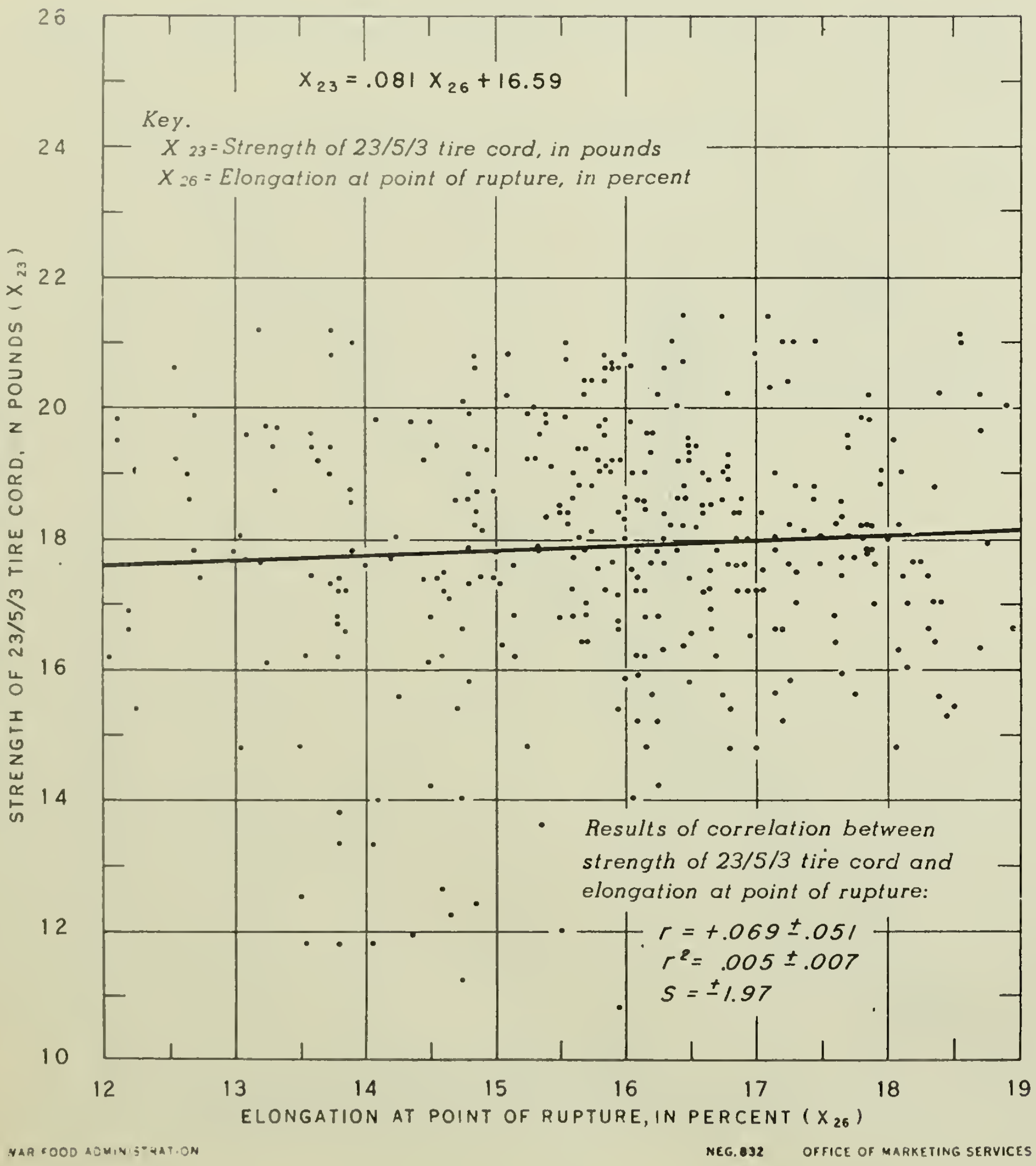


FIGURE 23 – Relationship between Strength of 23/5/3 Tire Cord and Percentage of Elongation at Point of Rupture

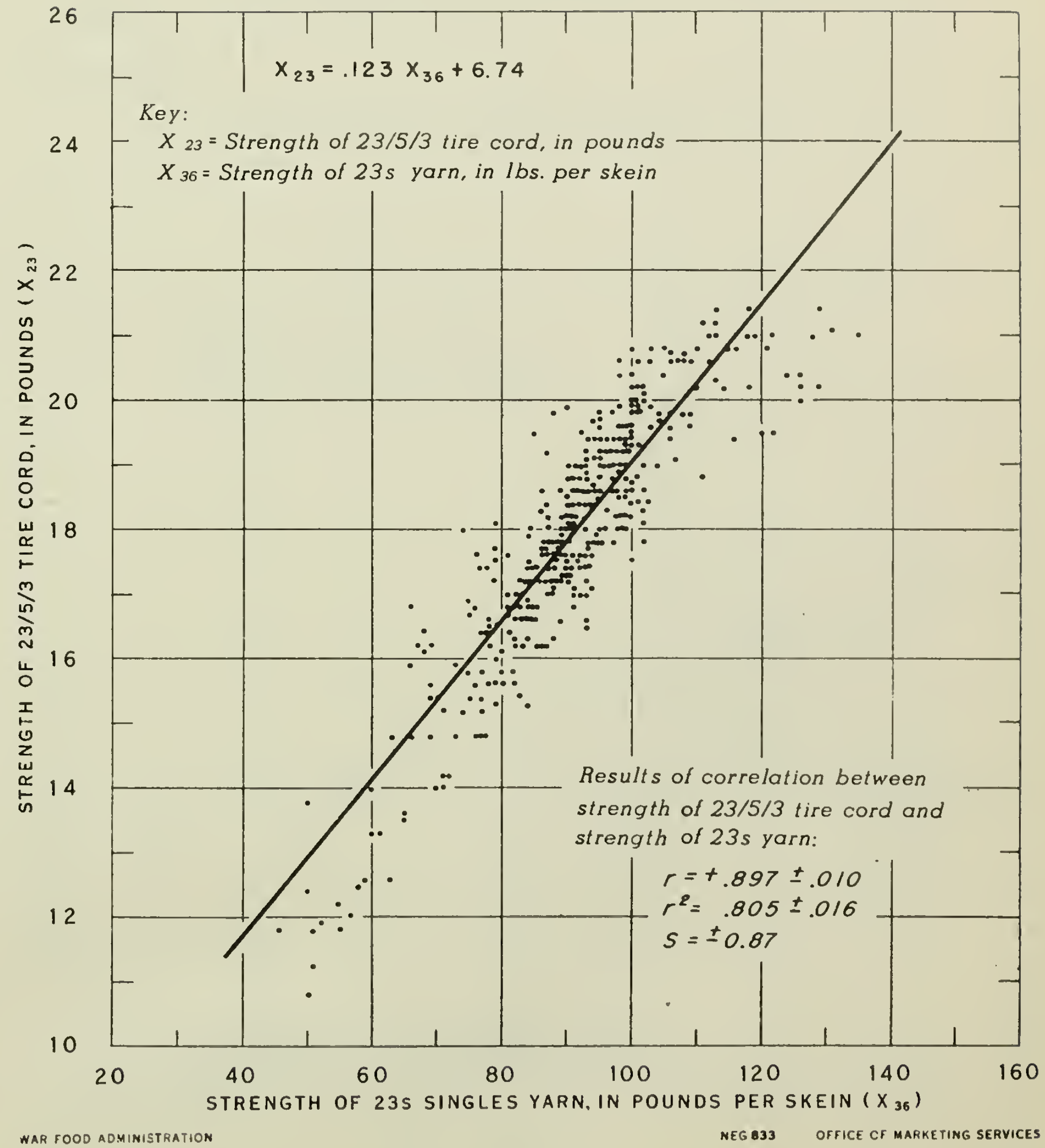


FIGURE 24 – Relationship between Strength of 23/5/3 Tire Cord and Skein Strength of 23s Singles Yarn

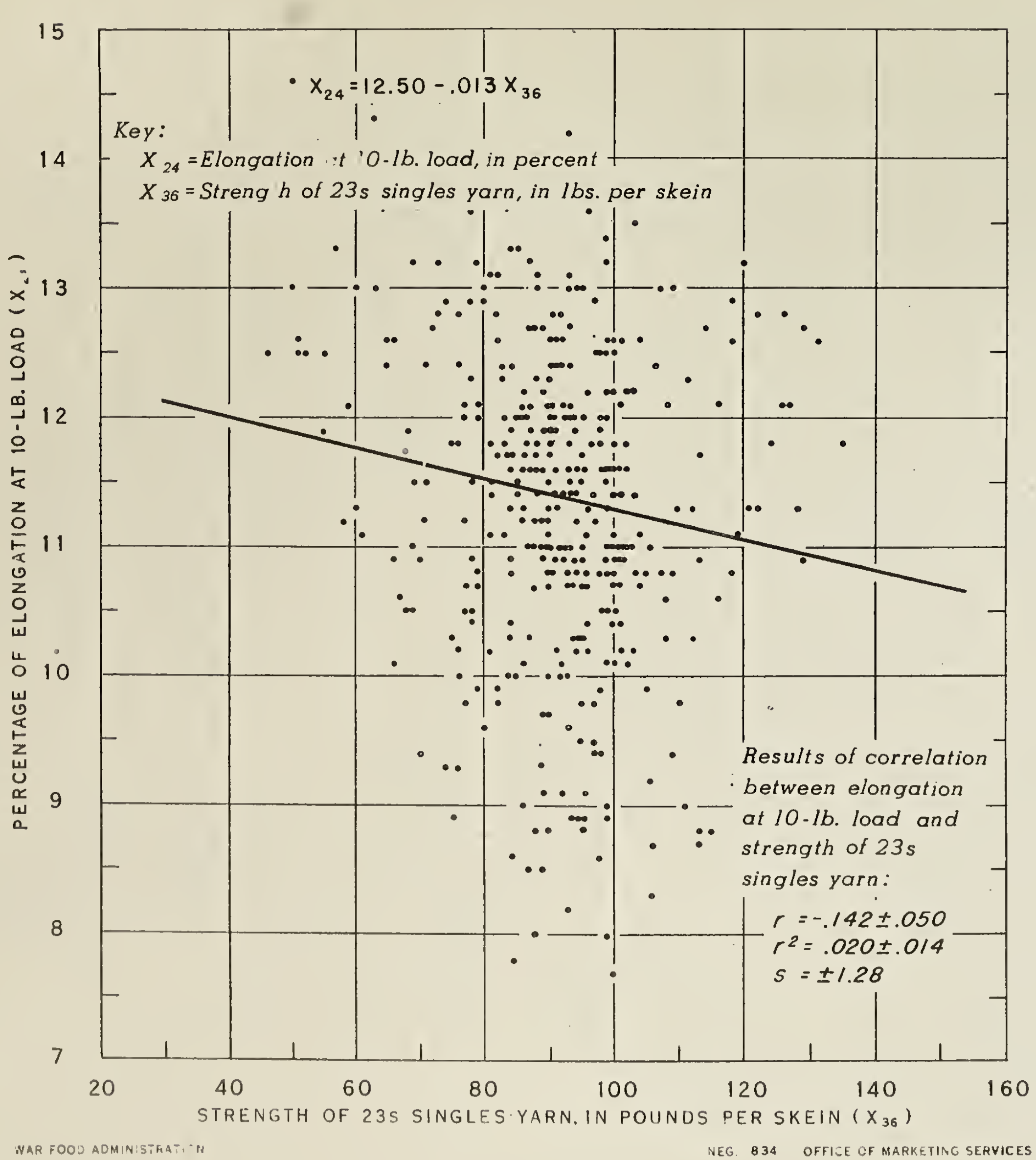


FIGURE 25 – Relationship between Elongation of 23/5/3 Tire Cord at 10-lb. Load and Skein Strength of 23s Singles Yarn

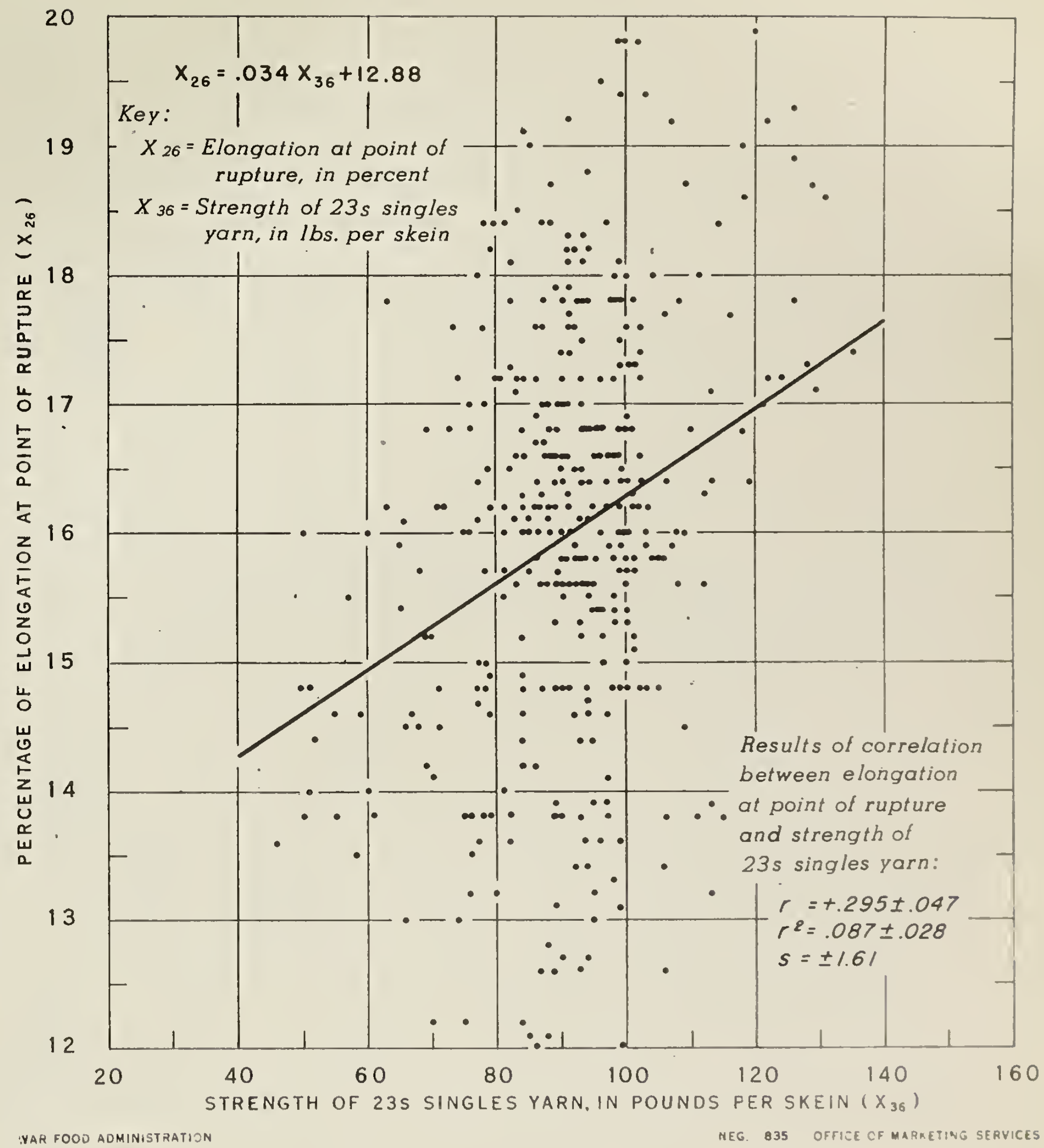


FIGURE 26 – Relationship between Elongation of 23/5/3 Tire Cord at Point of Rupture and Skein Strength of 23s Singles Yarn